| IN-LB | Inch-Pound Units |
|---|---|
| SI | International System of Units |

# Specifying Underground Shotcrete—Guide

Reported by ACI Committee 506

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Reported by ACI Committee 506

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*This document provides a guide for owners, contractors, designers, and testing, specifying, and inspection organizations engaged in the application of shotcrete for underground support. The guide provides general information for the selection of constituent materials, and methods to proportion shotcrete. Typical methods of batching, mixing, and handling of proportioned shotcrete materials are detailed along with shotcrete placement methods and equipment.*

**Keywords:** acceptance criteria; batching; inspection; methods of payment; mine(s); mixing; mixture proportioning; placement; quality assurance; quality control; safety; shotcrete; testing; tunneling.



## CONTENTS



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## CHAPTER 1—INTRODUCTION AND SCOPE

### 1.1—Introduction

In North America, the term "shotcrete" is used and defined by the American Concrete Institute's "ACI Concrete Terminology" as "concrete placed by a high-velocity pneumatic projection from a nozzle", while in Europe, shotcrete is commonly referred to as "sprayed concrete".

Shotcrete is ideally suited for underground applications in tunneling and mining as an initial support measure in soft ground as well as hard rock, as an installation method for final linings, or in underground rehabilitation or expansion projects.

The pneumatic projection of shotcrete onto a surface at high velocity provides specific quality enhancements that interact with the ground surface and prepared substrates, providing superior bond characteristics, increased density, strength, durability, and toughness. In addition, shotcrete provides the geometric and operational flexibility required for many underground operations and—especially if sprayed using robotic equipment—provides a safer working environment, compared to other support installation methods under unsupported ground or if immediate support is needed. These qualities are desirable in ground support and lining applications and provide economic and technical advantages compared to the other initial support systems and materials.

Cast-in-place (CIP) concrete is widely used in underground tunneling for final linings, especially if a constant cross section geometry over long distances allows the use of highly mechanized formwork. However, if the geometry is changing or the tunnel is too short to justify the investment for a mechanized formwork, shotcrete has many advantages over CIP concrete for final linings due to the inherent flexibility of the method to cover a large range of opening shapes and sizes. This allows for certain structures such as enlarged cross sections, intersections, or penetrations to be constructed with less effort in comparison to CIP concrete.

Geometrical flexibility for final linings is also a key advantage for rehabilitation and expansion projects. In addition, many of these projects are constructed under stringent operational limitations, providing, for example, very limited and strict time windows for construction. The operational flexibility of shotcrete allows for a stop-and-go installation of concrete and provides a key advantage of shotcrete to other installation methods.

Shotcrete technology has been broadly developed throughout the construction industry over the last century. The evolution of mining and civil tunneling methods has placed unique demands on the materials, equipment, and personnel that comprise current concepts of a shotcrete system for underground support and lining construction. With this gradual evolution in technology and trial and error came acceptance, adaptation, and new means and methods of successful shotcrete application.

The design, working conditions, and placement of shotcrete underground are unique, very demanding, and generally much more challenging than shotcreting above ground. The majority of underground shotcrete is installed overhead or sub-vertical, making the correct installation technique and strength development over time crucial.

The primary focus during shotcrete installation underground is worker safety, due to the need to provide immediate and effective ground support and to use proper installation procedures to avoid fallouts of fresh concrete. For the construction industry as a whole, the specification of a 28-day compressive strength is typically sufficient; however, the early strength performance of underground shotcrete during the first hours or days is often critical. Much of the shotcrete is applied overhead to irregular surface substrate profiles immediately following blasting or other modes of excavation. Geological and groundwater conditions are not always predictable; opening stability and rockfalls present a clear hazard to the underground workers. Conditions may be such that the window available for shotcrete application is minutes or a few hours. The use of accelerating admixtures is a unique feature of underground shotcrete application in that it provides a means of controlled and rapid strength gain immediately following application.

Tunneling or mining activities typically take place on a continuous and cyclical basis. The process of excavation, muck removal or mineral extraction, and ground support installation are repeated in every excavation and support round. To be viable and acceptable, shotcrete application should be an integral part of the overall cycle. This requires that the shotcrete system be reliable, efficient, and effective.

The underground environment can impose significant constraints and demands on the batching, mixing, handling, and placement of shotcrete. The unique logistical demands associated with underground shotcrete application may require access to the underground work area via shaft, adit, and ramp, and the subsequent use of long and restrictive haulage routes or dropping concrete through a borehole or slickline. This frequently results in extended handling and discharge times and may require the use of hydration-stabilizing admixtures and always requires a vigilant shotcrete crew to avoid plugs in slicklines and shotcrete equipment. At any time, production can be disrupted, and shotcrete installation delayed or disrupted. This is particularly problematic if ground conditions deteriorate and the demand for shotcrete as ground support becomes more critical. Finally, the environment can be hostile for worker safety, efficiency, and quality control, as well as for quality shotcrete placement and curing conditions. Figures 1.1a to 1.1c illustrate typical conditions at the heading of tunnels and mines.

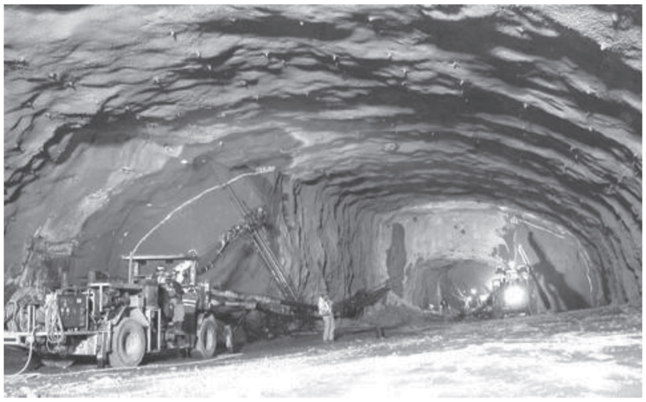

*Fig. 1.1a—Typical heading: large tunnel with drill rig.*

*Fig. 1.1b—Typical heading: small tunnel with drill jumbo.*

*Fig. 1.1c—Typical heading: mine.*

These types of challenges have led to specifically designed systems for batching and handling of shotcrete materials, admixtures, placement equipment, installation procedures, and training for underground shotcrete crews. These systems require significant investment not only in terms of capital, but also in providing experienced personnel. Further, the process is complemented by a holistic view on the part of the designer and specifier. Training and supervision have led to improvements in the quality and consistency of shotcrete in underground shotcrete applications. The consequences of deficient shotcrete in any ground support application are obvious and can be unsafe for workers. Quality assurance, quality control, and the associated inspection and testing activities are equally important in achieving a successful underground shotcrete program.

A major task faced by the underground shotcrete industry is the ability to demonstrate to owner, designer, specifier, and inspection and testing personnel that high-quality shotcrete can be produced consistently. It is therefore important that owners and others have an understanding and appreciation of how a shotcrete system—materials, batching, handling, placing equipment, and trained quality supervisory and production personnel—fits into their underground project to ensure that specification requirements are met. The efforts that go into designing, specifying, planning, and implementing a shotcrete program need to be commensurate with the size and complexity of the project. Many small projects require a basic, common-sense approach to quality for which a preconstruction testing and mockup program, which is typical for large and complex projects, may not be necessary. However, there are also small projects that involve a limited volume of shotcrete (for example, repair or rehabilitation) that are both complex and difficult, and where the quality requirements are clearly different. There are also many large underground projects throughout the world where a significant effort is required to staff and conduct extensive quality assurance programs, of which shotcrete is an important part. It is important that owners not be burdened with the cost of unnecessary inspection and testing requirements. For that reason, this guide carefully distinguishes the requirements associated with large, medium, small, and complex shotcrete projects to assist with identifying the optimal approach for the contemplated project.

## 1.2—Scope

Successful application of underground shotcrete requires teamwork and cooperation of all participants involved in the project. This guide is intended to provide a common basis, information, and background on the application of underground shotcrete for interested owners, designers, specifiers, and inspection and testing personnel.

The guide briefly discusses the concept of composite ground support—the combination of shotcrete and other