



Concrete Craftsman Series

Shotcrete For The Craftsman



CCS-4(20)



American Concrete Institute
Always advancing

Concrete Craftsman Series

Shotcrete For The Craftsman

Reviewed on behalf of ACI's Educational Activities Committee by:
ACI Committee E703

John L. Hausfeld, Chair

Scott M. Anderson

Paul J. Beagley

Aron J. Csont

Daniel P. Dorfmueller

James J. Ernzen

Leonard J. Gagliardi

Beverly A. Garnant

Michael G. Hernandez

William D. Palmer

Frank Townsend

Thomas G. Tyler

Kimberley E. Wilson

This education document for the shotcrete craftsman was prepared by ACI Committee E703, Concrete Construction Practices, with substantial input from ACI Committee C660, Shotcrete Nozzleman Certification, and is based on the previous booklet prepared by Jean-François Dufour, Marc Jolin, Lars Balck, Steven Gebler, Merlyn Isaak, Dudley Morgan, and Philip Seabrook. Review of this education document was performed by the above-mentioned original authors and additional ACI C660 members including Charles Hanskat, Raymond Schallom, Oscar Duckworth, and Randle Emmrich, who were all key in the improvement and support of this new document.

The authors would like to both recognize and thank all ACI C660 members for their dedication to the improvement of shotcrete practices throughout the industry, with thanks to Merlyn Isaak who was C660 Chair during development and launch of the ACI Shotcrete Nozzleman Certification Program in 2001. Special recognition goes to Theodore Crom who was the inspiration for Shotcrete Nozzlemen Certification.

Concrete Craftsman Series:
CCS-4 Shotcrete For The Craftsman
ISBN 978-1-64195-113-5
Copyright © 2020 American Concrete Institute

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

Managing Editor: Katie A. Amelio, P.E.
Engineering Editors: Katie A. Amelio, P.E.
Technical Editors: Emily Bush
Art Program: Robert Hogston and Aimee Kahaian
Production Editors: Kelli Slayden, Kaitlyn Dobberteen,
Tiesha Elam, Hannah E. Genig
Page Design & Composition: Ryan Jay
Manufacturing: Marie Fuller

First Printing: October 2020
Printed in Eau Claire, Wisconsin.

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
USA
www.concrete.org
+1.248.848.3700

CONTENTS

PREFACE	7
----------------	----------

CHAPTER 1—WHAT IS SHOTCRETE?

1.1—Introduction	9
1.1.1. Dry-mix shotcrete	9
1.1.2. Wet-mix Shotcrete	10
1.1.3 Comparison of the shotcrete processes	10

CHAPTER 2—WHAT THE SHOTCRETE CRAFTSMAN SHOULD KNOW ABOUT CONCRETE

2.1—What is concrete?	13
2.1.1 Aggregates	13
2.1.2 Paste	14
2.2—Fundamentals of concrete	15
2.2.1 Freshly mixed concrete	16
2.2.2 Workability	16
2.2.3 Consolidation	17
2.2.4 Hydration, setting time, hardening	17
2.2.5 Curing	18
2.2.6 Drying of concrete	18
2.2.7 Strength	19
2.2.8 Unit weight (density)	20
2.2.9 Resistance to freezing and thawing	20
2.2.10 Permeability and impermeability	20
2.2.11 Abrasion resistance	21
2.2.12 Shrinkage	21
2.2.13 Control of cracking	21

CHAPTER 3—CONCRETE MATERIALS

3.1—Cements	23
3.1.1 Portland cements	23
3.1.2 Special cements	25
3.1.3 Calcium aluminate cement (CAC)	25
3.2—Supplementary cementitious materials (pozzolans)	25
3.3—Aggregates	26
3.3.1 Maximum size of aggregate	27
3.3.2 Aggregate gradation (size distribution)	27
3.3.3 Harmful materials in aggregate	29
3.4—Mixing water	29
3.5—Admixtures	29
3.5.1 Accelerators	30
3.5.2 Set retarders	30
3.5.3 Water reducers	30
3.5.4 High-range water reducer	31
3.5.5 Air-entraining admixtures	31
3.5.6 Hydration control admixtures	31
3.5.7 Rheology-modifying admixtures	31
3.5.8 Shrinkage-reducing admixtures	31

CHAPTER 4—SHOTCRETE MATERIALS

4.1—Shotcrete	34
4.1.1 Dry-mix shotcrete	34
4.1.2 Wet-mix shotcrete	35
4.2—Reinforcement	37
4.2.1 Reinforcing steel	38
4.2.2 Welded-wire fabric	38
4.2.3 Steel and synthetic fibers	39

CHAPTER 5—MIXTURE PROPORTIONING

5.1—Water-cementitious materials ratio	41
5.2—Concrete proportioning for shotcrete	43

CHAPTER 6—SHOTCRETE EQUIPMENT

6.1—Equipment layout	45
6.2—Equipment operation	45
6.3—Dry-mix equipment	45
6.3.1 Single- and double-chamber guns	45
6.3.2 Continuous feed rotary guns	46
6.4—Wet-mix equipment	46
6.5—Air compressors	47
6.6—Mixing equipment	49
6.7—Hoses and nozzles	49
6.8—Scaffolding	50
6.9—Auxiliary equipment	51
6.9.1 Air lance (blow pipes)	51
6.9.2 Predampeners	52
6.9.3 Water booster pump	53
6.9.4 Lighting	53
6.10—Operation	53
6.10.1 Dry-mix shotcrete	53
6.10.2 Wet-mix shotcrete	53

CHAPTER 7—PREPARATION BEFORE SHOOTING

7.1—Earth surfaces	55
7.2—Forms	55
7.3—Existing concrete or masonry	56
7.4—Reinforcing steel	57

CHAPTER 8—SHOTCRETE PLACEMENT PRINCIPLES AND TECHNIQUES

8.1—General	59
8.2—Dry-mix shotcrete	62
8.3—Wet-mix shotcrete	62
8.4—Horizontal surfaces	63
8.4.1 Dry-mix shotcrete	63
8.4.2 Wet-mix shotcrete	64
8.5—Corners	64
8.6—Vertical surfaces	65
8.6.1 Bench shooting	65
8.6.2 Vertical layers	65
8.7—Overhead surfaces	67
8.8—Encasing reinforcing steel	68
8.9—Crew responsibilities	69

CHAPTER 9—ENVIRONMENTAL CONDITIONS AND PRECAUTIONS

9.1—Cold weather	73
9.2—Hot weather	74
9.3—Wind	74
9.4—Plastic shrinkage cracking	74
9.5—Curing	75

CHAPTER 10—FINISH AND TOLERANCE CONTROLS

10.1—General	77
10.2—Tolerance	77
10.3—Finishing	77

CHAPTER 11—SAFETY

11.1—General	79
11.1.1 Cement burns	79
11.1.2 Inherent pressure risk	80
11.2—Equipment	82
11.2.1 Manlift	82
11.2.2 Dry-mix equipment	82
11.2.3 Wet-mix equipment	82
11.2.4 Hose line wear	83
11.2.5 Safety shroud	83
11.3—Communications	83

CHAPTER 12—TESTING/QUALITY CONTROL

12.1—Evaluating shotcrete material quality	85
12.2—Test panels	85
12.2.1 Material	85
12.2.2 Mockup panels	86
12.2.3 Finish	86
12.3—Care in handling and curing of shotcrete samples	86

APPENDIX A—DEFINITIONS 87

APPENDIX B—EVAPORATION RATE CHART 91

PREFACE

The purpose of this document is to provide the nozzleman an understanding of basic concrete technology and describe and illustrate how to properly place quality shotcrete.

Information in this workbook should be used as a guide to good practice. ACI 506.2, “Specification for Shotcrete,” and ACI 506R, “Guide to Shotcrete,” should also be consulted. Above all, the plans and specifications for a specific construction project must be followed.

CHAPTER 1—WHAT IS SHOTCRETE?

Shotcrete is concrete conveyed through a hose and pneumatically projected at high velocity onto a surface to achieve compaction. It is a method of placing concrete used primarily in vertical and overhead surfaces. Shotcrete allows construction of walls and other structures with no form or only a one-sided form. It is often more economical than form-and-pour concrete because of its versatility and substantially reduced formwork. Tanks, swimming pools, tunnels, mines, sculptured rocks, structural walls, high-rise basements, erosion control embankments, retaining walls, and shear walls are all examples of new concrete structures commonly built using shotcrete. In addition, a wide variety of concrete repairs also employ shotcrete.

Shotcrete can be placed at various thicknesses against one-sided forms (or existing concrete or masonry structures and rock, earth, or other surfaces). Thickness of the material placed varies depending on several parameters, further described in Chapter 8, Shotcrete Placement Principles and Techniques.

The nozzleman is the craftsman that physically directs the shotcrete placement of the concrete. The nozzleman has final responsibility for the quality of the placed shotcrete and is an extremely important member of the shotcrete crew. The nozzleman should have an understanding of the materials, equipment, safety procedures, and the proper placement techniques to produce high-quality, durable concrete.

Although this document is directed to the nozzleman, they are not the only important person involved in a shotcrete project. The owner, engineer, contractor, job superintendent, foreman, and shotcrete crew are all important. Only with the cooperation and dedication of everyone involved will a project be successful.

1.1—Introduction

The two shotcrete processes are dry-mix and wet-mix.

1.1.1. Dry-mix shotcrete

Dry-mix shotcrete is the process where a dry mixture of concrete materials is conveyed pneumatically (with air flow) through a delivery hose to the nozzle where water is added (Fig. 1.1.1).

In dry mix, all the concrete ingredients, except liquids, are thoroughly mixed together and then fed into a mechanical feeder or gun. The dry concrete material is then carried by compressed air flowing through the delivery hose to a

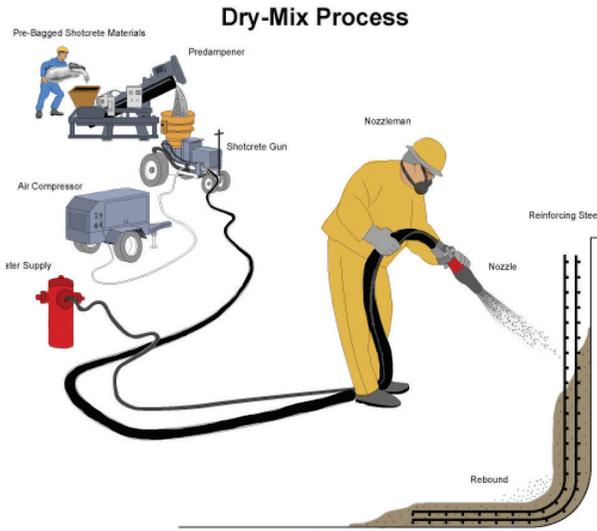


Fig. 1.1.1—Dry-mix shotcrete process.



Fig. 1.1.2—Wet-mix shotcrete.

nozzle body. The nozzle body has an internal water ring where water is injected under high pressure and thoroughly mixed with the concrete ingredients. The concrete is shot from the nozzle at high velocity onto the receiving surface. Mixing of all the concrete materials occurs in the nozzle and as the material impacts the surface.

The term gunite was once proprietary but has become a generic term. The American Concrete Institute adopted the term dry-mix shotcrete as a nonproprietary term for gunite and it is the terminology used in this document.

1.1.2. Wet-mix Shotcrete

The wet-mix process (Fig. 1.1.2) has all the ingredients—including cement, supplemental cementitious materials, chemical admixtures, aggregate, and mixing water—thoroughly mixed before being pumped into a delivery hose or pipeline. Compressed air is injected at the nozzle to increase the material velocity. The concrete is then shot from the nozzle at high velocity onto the receiving surface.

1.1.3 Comparison of the shotcrete processes

Either shotcrete process can produce quality shotcrete suitable for normal construction requirements. Different factors will determine the appropriate process for an application. These factors include experience of shotcrete crew, area of shotcrete to be applied, volume and thickness of shotcrete to be applied, jobsite access, availability of materials, and more.