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SPECIFICATIONS

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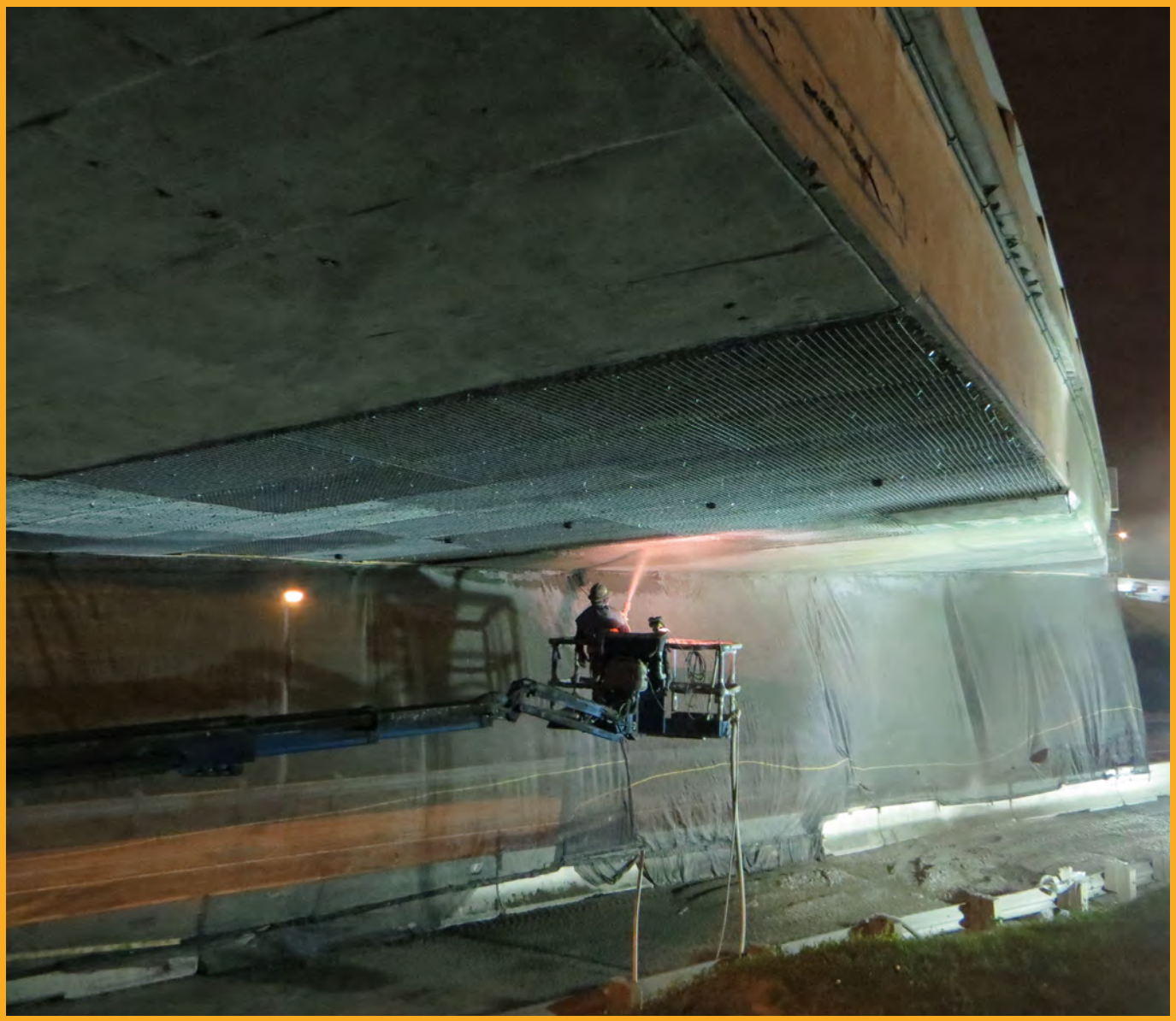

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FEATURES

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Editor's Note: Shotcrete is a placement method for concrete. However, for the sake of readability, the word "shotcrete" is often used either to identify the shotcrete process (method of placement) or the shotcrete mixture (product materials).

DEPARTMENTS

Shotcrete related standards for North America

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How Has ASA Helped You?

By Lars Balck

Five types of people are involved on nearly all shotcrete projects. To promote shotcrete, ASA has developed targeted programs to educate and help each member of the shotcrete project team:

1. Nozzleman: Administer the ACI Shotcrete Nozzleman certification program. ASA provides a mandatory education component for all new nozzleman candidates. Alice McComas coordinates sessions with hosts, examiners, and ACI. Both Alice and Charles Hanskat work with our ACI-approved ASA examiners to run the program at the host sites. Oscar Duckworth has been instrumental in helping to update educational material for the new nozzleman.
2. Contractor: Contractor Qualification (CQ) program. Chaired by Marcus von der Hofen, the Contractor Qualification committee developed and refined our Qualified Shotcrete Contractor program. Processing CQ applications depends on ASA staff and volunteer reviewers to thoroughly review contractor applications. We should also note Oscar also spear headed production of our Shotcrete Safety Guide lines that serve as a basis for contractor site-specific safety plans.
3. Inspector: The Shotcrete Inspector education program was spearheaded by Oscar and Charles. ASA members worked closely with ACI to finalize the ACI Shotcrete Inspector certification program. ASA often offers ACI inspector certification along with the full-day inspector education seminar, .
4. Engineer: ASA reaches out to engineers by offering complimentary "Introduction to Shotcrete" or our "Underground Shotcrete" seminars. We also publish the quarterly *Shotcrete* magazine and maintain many resources for specifiers on our website. This includes position statements, FAQs and a searchable archive of our past *Shotcrete* magazine articles.
5. Owner: As specifiers often work with or are the owners of a project, ASA also reaches out to these owners with similar resources.

ASA has established seven standing committees which rely on membership participation. The active work of our committees allows us to achieve our ASA goals. Each committee has a specific mission:

Education & Safety chaired by Oscar Duckworth: To gather and communicate safe practices and quality placement standards in the shotcrete industry. Work with ACI to produce an education program for Nozzlemen.

Contractor Qualification chaired by Marcus von der Hofen: To develop and maintain ASA's Contractor Qualification Program.

Marketing chaired by Ashley Cruz: To ensure that shotcrete has its "market share" in concrete construction.

Membership chaired by Jason Myers: To broaden and engage the ASA membership base.

Pool & Recreational Shotcrete chaired by Ryan Oakes: To educate and promote the proper use and application of shotcrete to the swimming pool and recreational shotcrete industry.

Underground chaired by Christoph Goss: To educate and promote the use and proper application of shotcrete to the underground construction and mining industries.

Technical chaired by John Zhang: To oversee the technical activities of ASA, including the review and evaluation of technical presentations, publications, handouts, etc., and the appraisal of research projects under consideration for ASA sponsorship.

In addition to the volunteers, ASA is fortunate to have an experienced full-time staff:

Charles Hanskat, our Executive Director, is also an ASA shotcrete nozzleman examiner. He often is called on for presentations about shotcrete to engineering firms, DOTs, universities, and other associations like ACI and ICRI. These presentations are needed because shotcrete has, for a number of years, been a forgotten or simply ignored process. He is also heavily involved in updating codes and standards that directly impact shotcrete, including ACI, ASTM, ICRI and AREMA.

Alice McComas is our Assistant Director who administers our nozzleman, inspector and contractor education programs. She is also heavily involved in our annual convention, committee meetings, membership and administrative functions of ASA.

Tosha Holden, is our marketing guru who manages two of our big programs. Our internationally recognized *Shotcrete* magazine and our Annual Outstanding Shotcrete Project Awards program. Tosha also creates and distributes our monthly email newsletter "What's in the Mix," submits

updates to our website, and handles all our social media including Facebook, Twitter, Instagram and LinkedIn.

To help the three ASA amigos, we utilize "Virtual," an association management firm to provide standard association functions like customer service, database management, web site maintenance, HR, event services and financial. So, if you see shotcrete communication coming via an email from Virtual Inc, know that they represent ASA to serve our members.

Another highly active member at ASA is Frank Townsend (currently serving as vice president) who has taken Charles' outreach initiative a step further. Frank is "getting them while they are open minded." Frank has gone to many universities to introduce engineering students to shotcrete and has developed a list of universities and contacts for future "Shotcrete 101" talks. Students are learning about many aspects of the construction world and open minded to alternate processes. Unfortunately, shotcrete is seldom a subject of most engineering and construction management curriculums. Frank and ASA want to change that.

As a volunteer organization, ASA is really a team that depends on everyone's input and help. Everyone (except for a few old shotcreters like me) has a full-time job which makes volunteering a challenge. Remember, the committee chairs are volunteers and always looking for additional members to help. Consider joining a committee and volunteering to help the chair either as secretary or as a task group leader. If you can't volunteer your time for a committee (or two) write an article for *Shotcrete* magazine to share your knowledge and experience with the industry. *Shotcrete* magazine is always open to contributors for articles. With the help of the entire membership, ASA can ramp up our promotion and adoption of shotcrete so "Shotcrete gets its fair share." By helping ASA, you in turn may well get your fair share. The more you help ASA the more quality shotcrete will be accepted.

In our nearly 25 years as an organization, ASA has accomplished much. We have promoted quality shotcrete placement and safety for our crews. We have made the design community much more aware of the benefits of shotcrete. We will continue to advance the industry. An association is only as good as its members. If you aren't already, consider becoming an active member on one or more of our committees to further the work of ASA, attend our convention to network with fellow shotcreters, submit a project for our Outstanding Shotcrete Project Awards program and/or write an article to convey your expertise, get some heightened visibility for you, your company and quality shotcrete. Be part of the ASA team as we advance the caliber and expanse of safe, sound shotcrete placement.

Underground Committee

By Christoph Goss, Chair

As the new chair of the ASA Underground committee, I have been working on getting up to speed with the Underground Committee's previous work under the guidance of the late Axel Nitschke. Under his leadership the committee prepared four position papers on important topics for underground shotcrete: *Spraying Shotcrete Overhead in Underground Applications, Spraying Shotcrete on Synthetic Sheet Waterproofing Membranes, Encapsulation of Reinforcement in Tunnel Shotcrete Final Linings,* and *Mechanical Application of Shotcrete in Underground Construction*. A fifth position paper, *Shotcrete Method for Innovative Materials in Underground Applications*, has been started. We are also proposing a sixth position paper focusing on the *Very Early Strength Shotcrete Testing for Underground Construction*. If either of these new topics are within your area of expertise and you would like to assist in the development of these papers, please email us at info@shotcrete.org. Our goal is to gather as much industry input as possible from our members from both North American and international practices.

Another key goal is better collaboration with other associated organizations. Thanks to a kind invitation by chair Lauro Lacerda, I'm now involved with the Underground Construction Association of SME USA Working Group 12: Spayed Concrete Use, which is tied to the International Tunneling Association Working Group of the same name. Several of our underground committee members are also active with the UCA committee. The goals of the ASA and UCS/ITA groups are very similar; hence I see a real opportunity to collaborate across both groups so we can get more mileage out of research and position papers. These are all volunteer positions, so let us not duplicate effort. If anyone reading this knows of another organization that works with underground shotcrete, send us an email at info@shotcrete.org.

Within the shotcrete community, the mining and underground construction industry relies heavily on remotely manipulated sprayers. This leads to problems when a nozzleman is required to be certified but has most or all of his experience with remotely manipulated nozzles and therefore may not quality for the ACI shotcrete nozzleman certification. The basic ACI shotcrete nozzleman certification for new nozzlemen requires a minimum of 200 hours of hand nozzling experience. The European Federation of National Associations Representing for Concrete (EFNARC) has a certification program for remotely manipulated spraying that includes a classroom session with exam, VR practice, actual spraying with equipment, and 40 days documented experience. However, unlike ACI certification, currently EFNARC does not evaluate the in-place quality of the shotcrete placement. Both the UCA and ASA committees plan to further explore EFNARC's efforts and see where there might be an opportunity to work together towards a program which brings together certification goals from each of these organizations.

Preparatory work is also underway to offer a shotcrete short course at the Rapid Excavation and Tunneling Conference 2023 and running a 3-day short course in Fall 2023 in conjunction with Deep Foundations Institute, UCA and Colorado School of Mines. Stay tuned!

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Shotcrete Inspector Education and Certification — Who, Why, How and When

By Charles S. Hanskat, PE, FACI, FASCE, ASA Executive Director

So, you've been inspecting concrete construction forever, but you were just assigned to a project that has this new type of concrete placement: "shotcrete." Shotcrete is just a placement method for concrete right? Well, that is true BUT there are many differences in the concrete materials, equipment and application techniques as compared to the old standard "form-and-pour."

First what is shotcrete? American Concrete Institute, Concrete Terminology (CT-21) says, "concrete placed by a high-velocity pneumatic projection from a nozzle." And what is high velocity? Research shows material is projected from the nozzle at 60 to 80 mph (100 to 130 kph). And is shotcrete really a new product? No, actually the basic process was invented in 1907, so shotcrete placement is over 100 years old. Over the century of experience, we have refined and improved shotcrete materials, equipment, and placement techniques to help us use shotcrete placement to produce quality concrete in a wide variety of concrete structures.

ASA SHOTCRETE INSPECTOR EDUCATION

With the strong growth of shotcrete construction, the concrete construction industry needs on-site inspectors who are knowledgeable about shotcrete materials, equipment, application, and quality. Although an inspector may be thoroughly experienced in the inspection of form-and-pour concrete construction, shotcrete has fundamentally different equipment, material selection, crew responsibilities, application techniques, testing, curing, and protection that need to be considered for producing high-quality and durable concrete structures with shotcrete placement.

ASA's Shotcrete Inspector Education program covers over 40 critical elements of shotcrete applications that on-site inspectors must know to properly evaluate and sign-off on acceptance documents for shotcrete. These include an overview of material selections, equipment, placement techniques, finishing, curing, protection, testing, and safety as it relates to the building official or inspector. Upon completion of the course, the Inspectors should have:

- A fundamental understanding of the wet- and dry-mix shotcrete processes.
- Current knowledge of ACI reference material and other industry standards pertaining to acceptable shotcrete placement.
- Industry-specific knowledge to determine if materials, and methods, as well as testing used by the crew meet shotcrete project specifications.
- Sufficient insight to recognize satisfactory application techniques, and actions that may reduce quality of the final product.

So, what members of the construction team would benefit from the ASA education? Obviously concrete construction inspectors or transportation construction inspectors where shotcrete may be used on current or future projects. It may also be helpful for the testing laboratories who have ACI Concrete Field Testing Technicians—Grade I, and may be expected to be called on for shotcrete testing or inspection. We also find value for engineers or specifiers who desire to learn more about quality shotcrete placement on their projects.

This education is also known as, "Quality Shotcrete – how to recognize it when you see it." For those not pursuing Shotcrete Inspector Certification, the education is also beneficial for project owners – to better recognize quality placement on their projects; and shotcrete contractors – to better communicate the quality application of their work to inspectors or project owners. In the pool and recreational shotcrete markets, we find this is especially important as many contractors in this market have not invested in the training and education necessary for quality placement. General contractors who regularly subcontract the shotcrete portion of their projects, should be able to recognize quality placement. Shotcrete contractors might know what to look for, but lack the knowledge to communicate clearly the what and why behind the visual indicators present in their work. Thus, this education serves a broad audience and helps raise the bar on quality shotcrete application by making quality applications more recognizable.

The full-day ASA Shotcrete Inspector seminar has been approved to qualify the attendee for the equivalent of one year of shotcrete inspection experience.

ACI SHOTCRETE INSPECTOR CERTIFICATION

ASA members worked closely for a number of years with ACI to develop the ACI Shotcrete Inspector certification. The goal of the certification is that an owner or specifier can request or require an inspector on a shotcrete project and know that the certified inspector has demonstrated proper work experience, met the prerequisites, and passed a rigorous written exam covering all aspects of shotcrete construction.

ACI's definition of a certified shotcrete inspector is: A certified Shotcrete Inspector is an individual who has demonstrated the knowledge and experience required to properly inspect the placement of shotcrete. The Inspector must understand the responsibilities and qualification requirements of the Nozzleman as well as the inspection requirements as cited in the documents governing the construction of the project.

The program requires a working knowledge of the following documents:

- ACI 305R-10, Guide to Hot Weather Concreting
- ACI 305.1-14, Specification for Hot Weather Concreting
- ACI 306R-16, Guide to Cold Weather Concreting
- ACI 306.1-90(02), Standard Specification for Cold Weather Concreting
- ACI 506R-16, Guide to Shotcrete
- ACI 506.1R-08, Guide to Fiber-Reinforced Shotcrete
- ACI 506.2-13, Specification for Shotcrete
- ACI 506.4R-94(04), Guide for the Evaluation of Shotcrete
- ACI 506.6T-17, Visual Shotcrete Core Quality Evaluation
- ACI CCS-4(08), Shotcrete for the Craftsman
- ASTM C1140/C1140M-11 – Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels
- ASTM C1604/C1604M-05(12) – Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete
- ASA, Safety Guidelines for Shotcrete

ACI sells a discounted package of the ACI documents listed (ACI CP61PACK – Reference Pack for Shotcrete Inspectors). The written exam is a 90-minute open book test. The ACI, ASTM and ASA documents listed above are the complete document references for the shotcrete knowledge tested in the exam. This is an excellent compilation of shotcrete knowledge that is great to have readily available on any shotcrete project.

Note that some of the documents have been revised since the compilation for the shotcrete inspector exam so may not be the most current available. However, all the exam questions come from these source documents.

ACI will grant certification only to those individuals who:

1. Obtain a passing grade on the written examination; and
2. Fulfill the requirements in ACI Concrete Field Testing Technician—Grade I as follows:
   a. Be currently certified as an ACI Concrete Field Testing Technician—Grade I
      OR
   b. Have been certified as an ACI Concrete Field Testing Technician—Grade I at one time
      AND
   c. Pass the current ACI Concrete Field Testing Technician—Grade I written exam within one year of passing the Inspector exam.*
3. Demonstrate three (3) years of satisfactory education and work experience.

Satisfactory work experience must include at least one of the following:

- Testing, inspection, and quality control of shotcrete;
- Supervision of shotcrete construction work;
- Design of shotcrete structures.

Certification is good for five years after completing all the requirements. You can find all the details of the certification process under the Certification tab on ACI's website (www.concrete.org).

SCHEDULING EDUCATION OR CERTIFICATION

Though the ASA Education seminar is equivalent to one year of work experience there is still a requirement for two more years of work experience. After taking the written exam you have one year to complete your application for full certification. Thus, we recommend not taking the certification exam until you have the required work experience (2 years with completion of the ASA education or 3 years without the ASA seminar).

How do you find an ASA shotcrete inspector seminar? You can check our calendar (www.shotcrete.org/Calendar) or the "Available Events" link under the Education/Certification tab on the ASA home page. You are always welcome to send an email to info@shotcrete.org requesting future dates.

ASA will generally offer an option to take the ACI certification written exam after one of our education seminars. A few ACI chapters also offer the written exam only (no education seminar). ACI also has regional resource centers (West Coast and Midwest so far) that can offer the written exams. ASA has worked with the ACI Resource Centers on several occasions to offer the full-day education in conjunction with the ACI written exam.

SUMMARY

Shotcrete has been accepted as a placement method in ACI 318 and many structural concrete projects may now include shotcrete placement. Though inspectors may have a wealth of concrete knowledge the specifics of shotcrete placement introduce a new set of variables and visual aspects the inspector must know to evaluate the quality of shotcrete placement during the shotcreting process. ASA education and ACI certification together provide the owner and specifier a higher comfort level of quality assurance with shotcrete placement on their projects.

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Fibre Spray Concrete: Testing and Performance Criteria

By Benoit De Rivaz

ABSTRACT

Sprayed concrete technology has dramatically improved with the use of advanced admixtures and placement methods to give durable and high-performance concrete. With improvements in sprayed concrete quality, tunnel linings can now be constructed using permanent fiber reinforced sprayed concrete instead of conventional cast-in-place concrete, lowering costs and significantly reducing the construction time, particularly in sections of complex geometry.

Modern sprayed concrete technology provides the tunneling industry with a more economic tunnel lining system by use of a single shell of permanent sprayed concrete. This technology provides a structural lining that is durable, watertight and can be surface finished to a degree that is similar to cast concrete.

The use of Fiber Reinforced Permanent Spray Concrete Lining (FRPSCL) allows the designer to eliminate traditional reinforcement. Over the last few years, the use of this technology has increased. One of the aspects boosting the use of FRC is the introduction of guidelines for the design of FRC. In 2013, the fib presented the fib Model Code 2010[1] that included a specific part on FRC. This document sparked great interest in the tunnelling community and several documents consider fib Model Code 2010 as a reference. This article intends to support the designer, contractors and owners in introducing FRSCL in future projects by establishing the existing state-of-the-art to specify proper performance and the appropriate testing method based on the just published revision of the European EN standards EN 14 487-1[2] and EN 14 488-3[3]. This article will underline, as mentioned in EN 14487-1, the different ways of specifying the ductility of fiber reinforced sprayed concrete in terms of residual strength and energy absorption capacity.

INTRODUCTION

The global sprayed concrete market has seen increased demand for construction technology for tunnel linings and mining operations. Sprayed concrete, aimed at replacing cast concrete in a variety of applications, has experienced great success. The need for increased productivity and safety has increased the use of more automated equipment with complex designs. This has increased the requirement for more sophisticated materials with different performance levels. Shotcrete material has distinct advantages with its high production rates, ability to conform to multiple shapes, and recyclability.

Traditional excavated tunnels (drill and blast) are used in civil engineering. Conventionally, tunnels constructed using sprayed concrete have been based on a temporary sprayed concrete lining to stabilize the opening soon after excavation and to contain short to medium-term loads. When this lining has fully stabilized, a permanent cast-in-place concrete lining is installed to carry long-term loads, provide durability, and water tightness.

A waterproof membrane between the temporary and permanent lining was commonly used to provide watertightness. This is referred to as the "double shell method." However, sprayed concrete technology has dramatically improved with the use of advanced admixtures and placement methods to give durable and high-performance concrete in a combined approach.

With this improvement in sprayed concrete quality, tunnel linings can be constructed using permanent steel fiber reinforced sprayed concrete (SFRC) instead of conventional cast-in-place concrete for the permanent concrete linings, lowering costs and significantly reducing the construction time, particularly in sections of complex geometry such as step plate junctions.

Modern sprayed concrete technology equips the tunneling industry with a more economic tunnel lining system by using a single shell of permanent sprayed concrete. This technology provides a structural lining that is durable, watertight and can be surface finished to a degree that is similar to cast concrete. The use of Fiber Reinforced Permanent Sprayed Concrete Lining (FRPSCL) allows elimination of traditional reinforcement in the precast segment production. Over the last few years, the use of this technology has been well proven.

Today there is a window for a more sustainable product considering the following aspects:

- Increased concrete material technology
- Slender and efficient structures
- High performance steel fiber: hardening post crack behavior at lower dosage
- Corresponding reduced consumption of resources
- Understanding and using the composite nature of concrete and rock mass
- Sensor technology for accurate placement and follow-up of status/conditions
- High efficiency and machine utilization
- Competence driven in all aspects

1. MATERIAL

Fiber Reinforced Concrete (FRC) is a composite material characterized by a cementitious matrix and discrete fibers (discontinuous). The matrix is either made of concrete or mortar. Fibers can be made of steel, polymers, carbon, glass or natural materials.

The longer the fiber, the better the bond of the steel fibers in the matrix and the more difficult to pull the fiber out of the matrix. It is generally recommended to use a fiber length of at least three times the size of the maximum aggregate used in the cementitious matrix. The smaller the fiber diameter the higher the number of fibers per unit weight and the more efficient the reinforcement becomes and produces smaller crack widths. Steel fibers with a high length/diameter ratio have a better performance.

1.1. Hooked ends

Tensile stresses induced in the concrete are transferred to the steel fibers thanks to the durable bond characteristics between both materials. The bond can be improved by enhancing the mechanical anchorage and choosing a suitable shape of the steel fibers. Hooked ends, enlarged ends, and crimped wire are examples of different shapes available on the market.

1.2. Tensile strength

An efficient load transfer will result in a high tensile stress in a small diameter steel fiber. Efficient steel fibers need to have a high tensile strength to avoid fiber fracture. The use of high strength concrete and shotcrete have enhanced the need to develop high tensile steel fibers.

1.3. Glued fibres

Good fibers should have a high length/diameter ratio. This can however cause problems when mixing into the concrete. Loose fibers, particularly those with a high length/diameter ratio, are difficult to spread evenly in the concrete mixture. Bekaert has overcome this problem of "fiber balling" by gluing the Dramix® fibers. The gluing of the fibers into bundles guarantees quick and easy mixing for a homogeneous distribution and good dispersion throughout your concrete.

The properties of the composite depend on the physical characteristics of the constituent materials as well as on their dosage. Other factors such as the geometry, volume fraction and mechanical properties of the fibers, the bond between fiber and concrete matrix, as well as the mechanical properties of the matrix, significantly affect the FRC properties.

1.4. Behavior

The behavior of fiber reinforced concrete is more than a simple superposition of the characteristics of the concrete matrix and the fibers. To analyze the behavior of this composite material requires considering the interaction between both, basically considering the transfer of loads from the concrete matrix to the fiber system.

For efficient load transfer, the following three conditions must be satisfied:

- Sufficient exchange surface (number, length, diameter of fibers).
- The nature of the fiber-matrix interface which would allow for proper load transfer.
- The intrinsic mechanical properties (Young's modulus, anchorage type and tensile strength) of the fiber, which allows the forces to be absorbed without breaking or excessively elongating the fiber.

In fact, in a hyperstatic mechanical system, the better the cracking is "controlled" as soon as it arises (small crack widths), the better the multicracking process ... resulting in the structure tending to show ductile behavior.

According to ISO 13270: "Steel fibers are suitable reinforcement material for concrete because they possess a thermal expansion coefficient equal to that of concrete, their Young's Modulus is at least 5 times higher than that of concrete and the creep of regular carbon steel fibers can only occur above 370 °C (700 °F)." Optimizing the creation of an FRC with a high fiber dosage does not pose any technical problems as such. This aspect is managed just as easily as the use of other cementitious materials in the concrete matrix. The method consists in finding the optimal granular skeleton (optimal coarse/fine aggregate ratio) that produces the best workability, for a given type and percentage of fibers. Theory and experience both show that the most workable SFRC is the most compact, as well as the strongest and most durable. Practically, the method always uses an already optimized concrete mixture, called the "reference concrete," as the basis for the enhanced mixture.

Compared with this reference concrete, optimized SFRC has:

- a greater coarse/fine aggregate ratio.
- more cementitious paste and/or superplasticizer.

Thus, the higher the fiber percentage, the greater the length-diameter ratio of the fiber and the length of the fiber, the greater the coarse/fine aggregate ratio, the greater the quantity of cementitious paste and percentage of superplasticizer needed.

2. TESTING AND PERFORMANCE CRITERIA

EN 14487-1 mentions the different ways of specifying the ductility of fiber reinforced sprayed concrete in terms of residual strength and energy absorption capacity. It also mentions that both ways are not exactly comparable.

The energy absorption value measured on a panel can be prescribed when – in the case of rock bolting – emphasis is put on energy to be absorbed during deformation of the rock. This is especially useful for primary sprayed concrete linings (EN 14488-5: Testing sprayed concrete, part 5: Determination of energy absorption capacity of fiber reinforced slab specimens).[4]

The residual strength can be prescribed when the concrete characteristics are used in a structural design model (pr EN 14488-3, Method B). For FRPSCL the residual strength will be the key material property to be determined,

2.1. Testing Method

The design of FRC structures, particularly of tunnels, is often made adopting the provisions of the fib Model Code as it is considered the reference document in several guidelines for tunnels. A practical method to determine the tensile behavior of SFRC for shotcrete applications is a 3-point bending test on square panels.

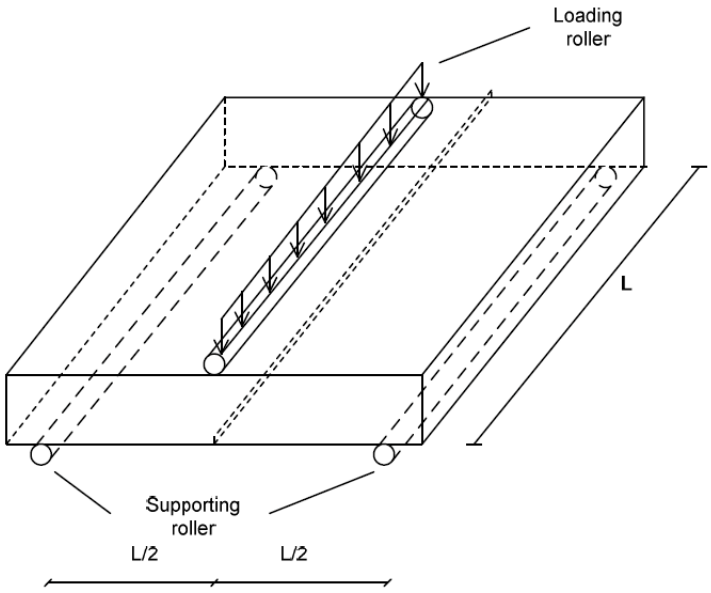

Fig. 1: *Testing set-up according to pr EN14 488-3*

This test combines the output of the EN 14651 with the advantages of the EN 14488-5 test (the same molds can be used and due to the larger cracked section, the scatter of results is lower). This test method is essentially the same as the EN 14651, but on a larger and thinner beam (panel). This test method was proposed to reduce the variability in the results from the notched beam while using a specimen that is closer to the actual conditions of the structure. For that reason, it uses the same specimen dimensions in the EN 14488-5, a 100 mm (4 in.) thick and 600 mm (24 in.) sided square panel. As for the EN 14651, the results from this test method could be used for structural design with fib's Model Code 2010. The results from this test method can also be used to calculate the stress-crack width relationship of FRS.

This test method has been investigated in recent research projects and showed good repeatability and reproducibility. However, the length on which the loading roller must be in continuous contact and its degrees of freedom can be an issue for FRS. Indeed, it is difficult in some cases (e.g. when using rapid set-accelerating admixtures) to produce completely flat specimens. Recent results from early investigation in different laboratories indicate that this is a suitable test for characterizing FRS. Given the distinct advantage that the specimen is produced using similar tests panels as the EN Plate (EN 14488-5) and requires minimum saw cutting, it should be expected to see more of this test method in replacement of the EN Beam test (EN-14651) Ref 5. In fact,

the early results show results comparable to those obtained with this beam tests, particularly for the degree of fiber content usually encountered in FRS for ground support.

2.2. Performance criteria

- *Ductility* verification is necessary to consider any benefit of steel fibers in the long-term; The design state-of-practice requires FRC to exhibit "deflection softening" behavior.
- *Deflection Hardening* is necessary to ensure the development of multi-cracking so that crack widths are controlled.

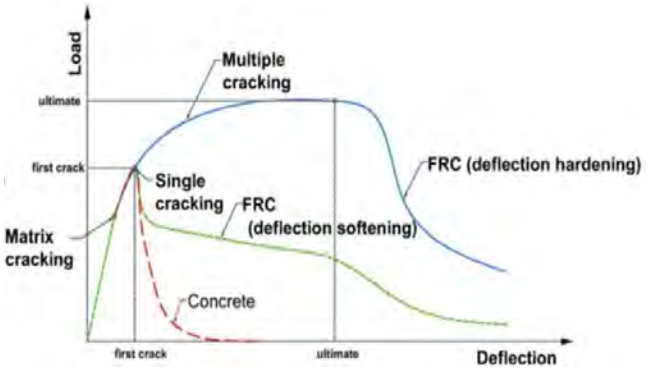

Fig. 2: *Ductility behavior*

Nominal values of the material properties are determined according to pr EN 14-488-3 Method B. The diagram of the applied force (F) versus the deformation should be produced, a typical diagram is shown (Fig. 3). The deformation is generally expressed in terms of Crack Mouth Opening Displacement (CMOD).

Parameters, $f_{R,j}$, representing the residual flexural tensile strength, are evaluated from the F-CMOD relationship, as follows:

$$f_{R,j} = \frac{3F_j l}{2bh_{sp}^2}$$

where:

f_{Rj} [MPa] is the residual flexural tensile strength corresponding to CMOD = CMODj
F_j [N] is the load corresponding to CMOD = CMODj
l [mm] is the span length;
b [mm] is the specimen width;
h_{sp} [mm] is the distance between the notch tip and the top of the specimen (125 mm [5 in.]).

The fiber reinforced concrete can be classified considering the compressive strength (with the same approach adopted for normal reinforced concrete) and the tensile post cracking performance measured at 28 days.

In particular, two parameters are used to describe the behaviour, namely fR1k (representing the strength interval) and a letter a, b, c, d or e (representing the fR3k/fR1k ratio). The strength interval is defined by two subsequent numbers in the series:

1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, ... [MPa]

while the letters *(a), (b), (c), (d), (e)* correspond to the residual strength ratios:

- if $0.5 \le f_{R3k}/f_{R1k} \le 0.7$
- if $0.7 \le f_{R3k}/f_{R1k} \le 0.9$
- if $0.9 \le f_{R3k}/f_{R1k} \le 1.1$
- if $1.1 \le f_{R3k}/f_{R1k} \le 1.3$
- if $1.3 \le f_{R3k}/f_{R1k}$

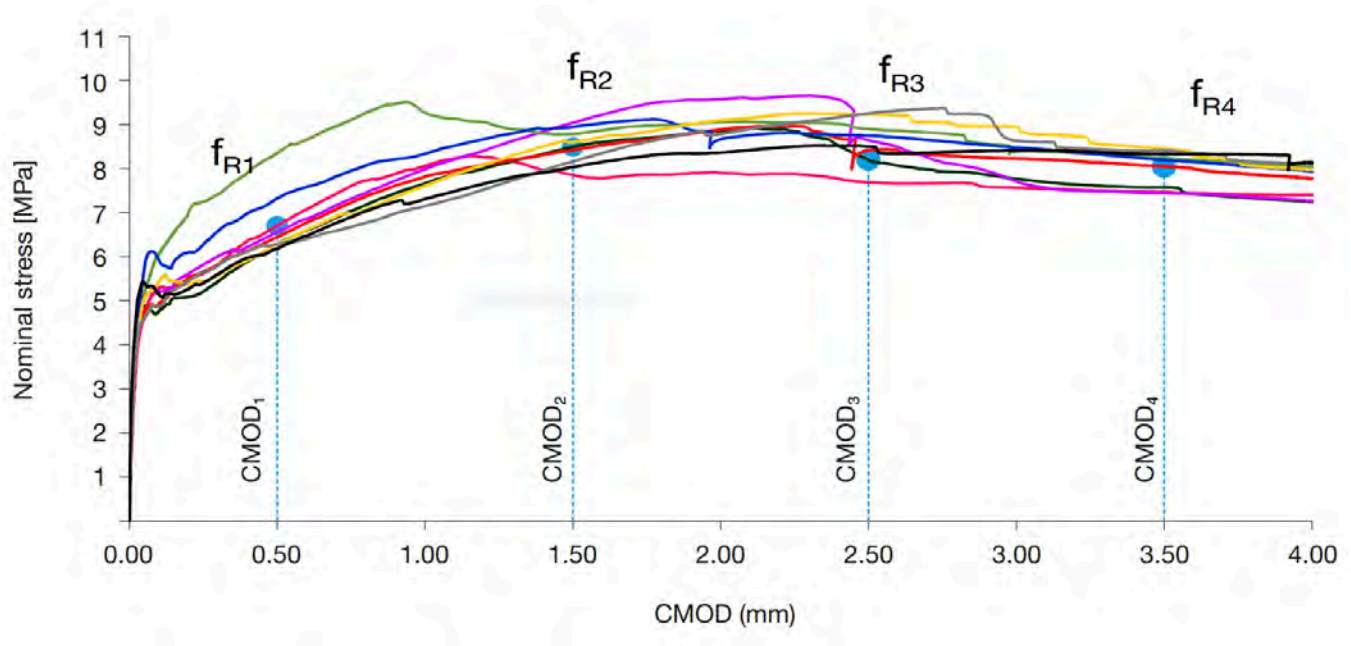

Fig. 3: *Load (Nominal Stress) deflection (CMOD) curve*

The designer should specify the residual strength class, f_{R1K} and the f_{R3k}/f_{R1k} ratio as well as the type of the fiber and its material properties such as fiber strength. The residual flexural strengths given in Table 1 may be determined according to EN 14488-3, method B or according to EN 14651, depending on the specification.

Table 1. Definition of class of ductility

Class of ductility	Ductility requirement	Crack control requirement
Class 1[a]	$f_{Rs3k}/f_{Rs1k} > 0,5$	$f_{Rs1k}/f_{Lsk} > 0,4$
Class 2	$f_{Rs3k}/f_{Rs1k} > 0,7$	$f_{Rs1k}/f_{Lsk} > 0,5$
Class 3	$f_{Rs3k}/f_{Rs1k} > 0,9$	$f_{Rs1k}/f_{Lsk} > 0,6$

[a] Class 1 for ductility and crack control requirement meets the requirements of the fib Model Code.

Depending on the application (structural or non-structural), crack control requirement must be specified accordingly. The statistical basis on which f_{Lsk}, f_{Rs1k}, f_{Rs2k} and f_{Rs3k} are to be determined shall be specified during preconstruction testing (section 7.3). Section 7.4.4 applies to production control and Section 7.5.2.4 applies to proof of conformity.

3. PROJECT EXAMPLE

The M4-M5 Link Tunnels in Sydney, Australia, is approximately 7.5 km (4.7 mi) long and accommodate up to four lanes of traffic in each direction with spans up to 23 m (75 ft) in the main lines and 34 m (111 ft) in transition caverns. It connects the New M4 Tunnels with the M8 Tunnels to form the 33 km (21 mi) long Westconnex Motorway, mostly underground. Like many road tunnels in Sydney, these tunnels are designed as drained structures and adopt Permanent Sprayed Concrete Linings for 100-year design life.

In wet sections of the tunnel, a sprayed waterproofing membrane was adopted where the primary lining is still designed to resist all ground loads and the applicable residual water pressure in the long-term. The secondary lining design is designed without relying on long-term shear transfer by the membrane to resist operational loads and, as a redundancy, also the residual ground water loads.

Fig. 4: M4-M5 Link Tunnels, Sydney, Australia

3.1. Sprayed concrete strength.
Primary & secondary lining 40 MPa (5800 psi), flexural tensile strength, fR1k= 3,5 Mpa (510 psi) and fR4k = 3.0 MPa (435 psi)

3.2. Lining thickness

- Primary lining: 110 mm (4.3 in.) with 35 kg/ m3 (59 lb/yd^3) of steel fibers
- Secondary lining: 125 mm (5 in.) with 35 kg/m^3 of steel fibers & 1kg/m^3 (1.7 lb/yd^3) polypropylene fibers for fire resistance

The use of high-performance end-hooked steel fibres Dramix® 4D 65/35BG was effective in achieving the desired high-level performance ground support characteristic design ***fr4 = 3.0 MPa***.

Production testing confirmed performance with only minor and, as expected, outliers. The high-performance fiber combined with the consideration of compressive membrane action (CMA) allowed for the design of very thin FRPSCL (t = 90 mm [3.5 in.]) with an assumed unbonded condition with high capacity demonstrated by both numerical modelling and large-scale field tests.

The consideration of CMA effects were confirmed by load-bearing capacities that were some 3-6 times greater than those estimated by conventional design methods based on pure flexural/bending resistance.

CONCLUSION

Steel Fibre reinforced sprayed concrete is a relevant material to be used for final linings.

All the relevant standards concerning the product, the testing, the design and quality control are available today to allow designers to specify the right performance. A good understanding of the material requires complete information on the FRC material property. For structural use, mechanical performance of FRC must be verified according to the fib Model Code 2010 requirements and material properties determined based on three-point bending test to limit the structural effect. A practical method to determine the tensile behavior of SFRC for shotcrete applications is a three-point bending test on square panels described in the pr EN 14 488-3. This test combines the output of the EN14651 with the advantages of the EN14488-5 test. The same molds can be used and due to the larger cracked section, the scatter is lower.

Quality and safety can be achieved using the relevant product for the application.

The final use of the shotcrete placement should be considered along with the test and performance criteria:

- Post crack behavior.
- Match crack widths and deformation in the test to expectations in the project and durability requirements

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Concrete Delivery Systems – What You Need to Know

By Michael Cetnar

Concrete delivery systems are used every day in the shotcreting industry. The big question is, "Am I using the right products?" If I have an accident or issue, "To what standard or regulation am I going to be held accountable?"

In the concrete pumping and shotcrete industry, there are few regulations that directly apply (except in British Columbia, Canada due to recently enacted legislation). In fact, there is almost no delineation in professional publications American Society of Mechanical Engineers (ASME) B30.27, Canadian Standards Association (CSA) Z151, American Concrete Institute (ACI) ACI304.2R, American Concrete Pumping Association (ACPA) Safety Manual, Schwing and Putzmeister owner's manuals that differentiate shotcrete pumping from concrete pumping. The only exception is dry-mix shotcreting. This is because dry-mix uses air flow to convey dry concrete materials through the delivery line instead of a hydraulic pump to push pre-mixed liquid concrete through the line.

Most safety professionals and safety organizations lean on ASME B30.27, if they are in the United States, or the CSA Z151 if in Canada. These would be the most common safety standards to which shotcrete pumping companies will be held accountable. The good thing is that the ASME and the CSA are in alignment with their safety standard publications. They nearly mirror each other in their writing and intent.

Shotcrete pumps have a machine tag on the equipment that usually states the maximum working line pressure exerted when pumping. If it is not on the machine, look in your owner's manual or contact the manufacturer of your machine. It is important to note that, maximum hydraulic pressure is related to working line pressure, but they are two different things.

The maximum concrete line pressure will be the basis for which delivery system is safe for you to use on the job. Line pressure will be highest when closest to the machine and will reduce as you pump farther away. Although the pressures are reduced farther away from the pump, if it plugs, the entire delivery system is quickly charged to the maximum line pressure of the concrete pump. This is why the delivery system is built around the maximum concrete line pressure of the machine. In the event of a plug, a lesser-rated delivery system can fail without warning, causing serious safety issues and potential property damage.

ASME B30.27 Section 27-1.10 and CSA Z151 Section 5.2.2.2 both state that all components of the delivery system must withstand the maximum material pressure of the connected pumping equipment. The owner's manuals of Schwing, Putzmeister, the ACPA safety manual and ACI 304.2R section 4.7.1 also have similar statements in them. These documents also note that all delivery systems components must have a minimum 2:1 safety factor for burst pressure when new.

The next component of having the proper delivery system is verifying that the product you are using meets the maximum working line pressure. ASME and CSA require all delivery line, hose, and accessories to be marked with the maximum working pressure when new. They also require that the labels have a manufacturer's part number, the internal diameter, and a weight per foot with concrete in it (Fig. 1). It is also important to contact the manufacturer of the delivery system to verify how to check wear on the components as they wear and get thinner. The delivery system must be inspected and tested regularly as it wears to verify that it can still hold the maximum working pressure of the pump.

Fig. 1

Clamps are especially important to check for pressure (Fig. 2). Most manufacturers cast the working pressure into the clamp to make sure they have a durable

Fig. 2

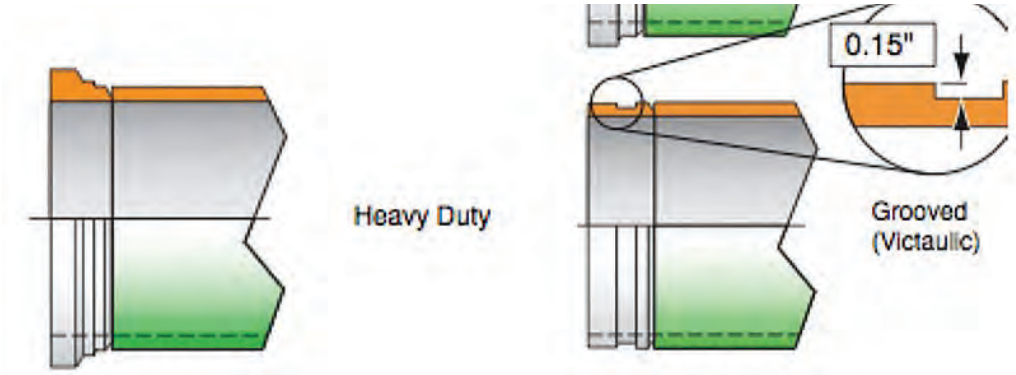


Fig. 3

marking that is easy to read and locate. Grooved end fittings are prohibited in concrete pumping applications by the ASME and CSA. Grooved connections have two issues that affect their ability to handle the higher pressure of today's shotcrete pumps. The groove does not have enough depth to hold the clamp in place to maintain the higher pressure at the required 2:1 or greater safety factor. The bigger issue with the grooved connection is that the groove is cut into the metal which is part of the material that is wearing as it is used. As the metal is worn down with use, the engagement area where the clamp is connected weakens and can fail without warning. Clamps that use a raised end (like HD or heavy duty) provide a safer connection and will have a much higher working pressure rating than grooved clamps (Fig. 3).

The last thing to consider in your delivery line selection is Concrete Pump Manufacturer's Association (CPMA) Certification. The CPMA audits the manufacturer or supplier of the components. They verify that the items have documentation and engineering data to back up the claimed pressure ratings. They also conduct laboratory testing to verify engineering data. This certification must be accomplished periodically to verify compliance to the ASME safety standard. This certification also gives you confidence that the ratings on your delivery system are what they state and not just a sticker stating the information.

It is strongly encouraged to get a copy of the ASME B30.27 or CSA Z151 Safety Standard depending on the area of North America in which you are working. Both publications have become the "standard" that the construction safety professionals use to promote safety.

Sources
ASME B30.27 -2019
CSA Z151 – 17
ACI 304.2R
ACPA Safety Manual v 7.0.1

Michael Cetnar *has worked in the concrete pumping industry for 27 years. His experience has encompassed boom trucks, and trailer pumps of various sizes as well as maintaining them. He has also worked as a concrete pump equipment manager for a top 10 general contractor in the US managing concrete and shotcrete pumps. Currently, Michael is a Regional Manager for Conforms covering key accounts in the US and Western Canada and conducts safety training for delivery systems for Conforms. British Columbia also recognizes him as an industry expert and has been actively helping them with their regulations.*

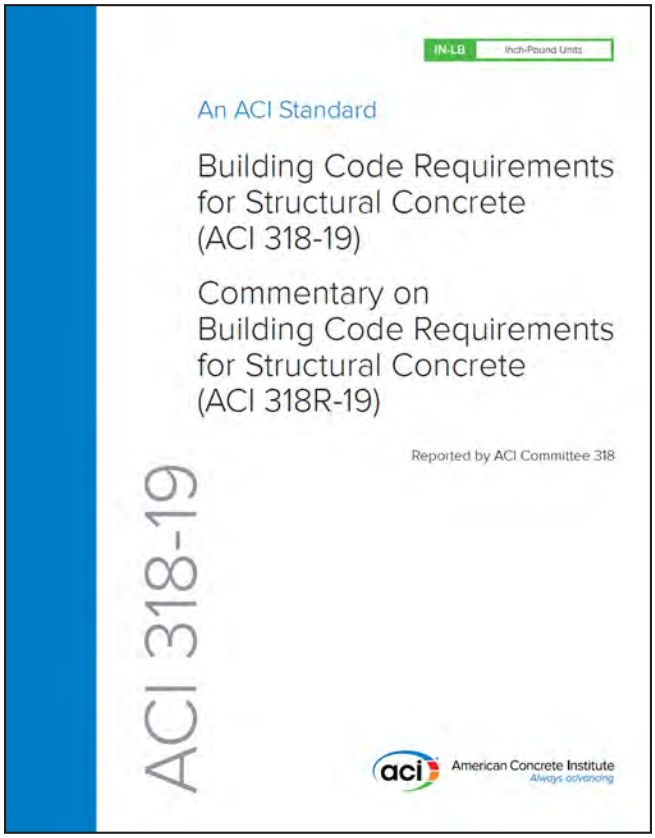
Codes, Construction Standards, Guides and Reports

By Lars Balck and Charles Hanskat

The American Concrete Institute (ACI) publishes a wealth of technical documents on concrete. The various documents are focused on the concrete industry as a whole but most are targeted directly for use by design engineers and contractors. Codes, construction standards, guides and reports are written for different members of the construction community. The target audience for specific documents may be designers, contractors, testing laboratories or inspection agencies.

ACI has two basic groups of documents, mandatory and non-mandatory language. Mandatory language standards, include codes, and construction specifications. Non-mandatory language documents that may include guides and reports. Generally mandatory documents are written in rather terse language meant to have only one interpretation. Non-mandatory documents can be much more verbose allowing them to cover their topics with a variety of styles and content.

All ACI documents are developed using a consensus committee procedure that helps assure the document is well vetted by active members in the industry. Committees that develop documents, especially the mandatory language documents, must strictly follow ACI Technical Committee Manual (TCM) that details the process and the required style.



ACI DESIGN CODES

Design codes are targeted to the design professional, not the construction team. ACI Technical Committee Manual (TCM) states for Code requirements:

> "An ACI code provides minimum requirements for concrete or masonry structures within its scope to safeguard public safety, health, and general welfare. Codes may be adopted by a model building code or by a regulatory agency or may be used by an industrial or governmental organization for which construction or manufacture of a work which uses concrete."

ACI Code documents include code requirements, code cases, acceptance criteria, and design specifications. ACI 318 Building Code Requirements for Structural Concrete and Commentary is one of the most widely used codes for design of concrete structures. However, there are many more ACI code documents that apply to specific types of concrete structures. These include documents like:

- ACI 307 Code Requirements for Reinforced Concrete Chimneys (ACI 307-08) and Commentary
- ACI 350 Code Requirements for Environmental Engineering Concrete Structures & Commentary
- ACI 376 Code Requirements for Design & Construction of Concrete Structures for Containment of Refrigerated Liquefied Gases & Commentary

It should be noted that some ACI codes do include content related to information the designer must convey through the contract documents to the contractor. For example, in Chapter 21 of the ACI 318-19 Code titled, "Construction Documents and Inspection" the scope plainly states:

"This chapter establishes the minimum requirements for information that must be included in the construction documents as applicable to the project. The requirements include information developed in the structural design that must be conveyed to the contractor, provisions directing the contractor on required quality, and inspection requirements to verify compliance with the construction documents."

This chapter is directed to the licensed design professional responsible for incorporating project requirements into the construction documents. The construction documents should contain all of the necessary design and construction requirements for the contractor to achieve compliance with the Code. It is not intended that the Contractor will need to read and interpret the Code."

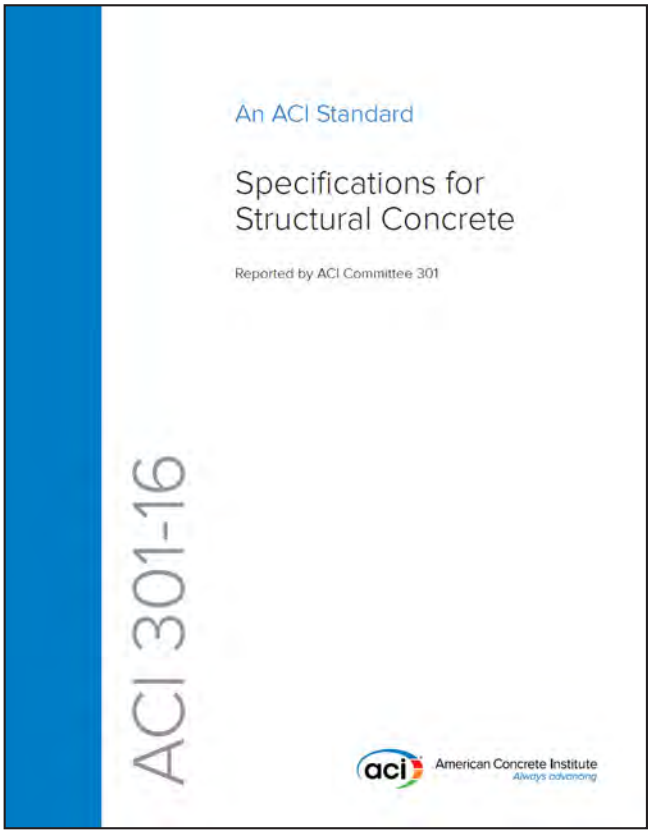
Note the last sentence. ACI 318 does not expect the contractor to be required to read or use the code. Again, that's up to the design professional.

Contractors are not expected to read or interpret ACI codes for their projects.

As an example of shotcrete-related information in ACI 318 that must be included by the design professional in the construction documents is Section 26.5.2.1 Compliance requirements that in subsection (o) states, "A certified shotcrete nozzle operator shall place all shotcrete." And then in the adjacent commentary section "R26.5.2.1(o) Nozzle operators become certified through testing and training programs that include written and performance examinations. Each shotcrete nozzle operator should be certified in accordance with the applicable ACI certification program for dry-mix or wet-mix shotcrete (both are covered by CPP 660.1-15)."

ACI CONSTRUCTION STANDARDS

On the other hand, ACI construction standards are written to direct the producers, testing agencies, and construction



team, not the design professional. However, often the construction standards are referenced or included in the contract documents for a construction project that are produced by the design professional to direct the contractor's work on the job.

ACI construction standards include construction specifications, material specifications, inspection services specifications, and testing services specifications. Additionally, test methods may be developed by an ACI committee but only when an ASTM standard test method has not been developed to cover the process.

Examples of ACI construction standards include:

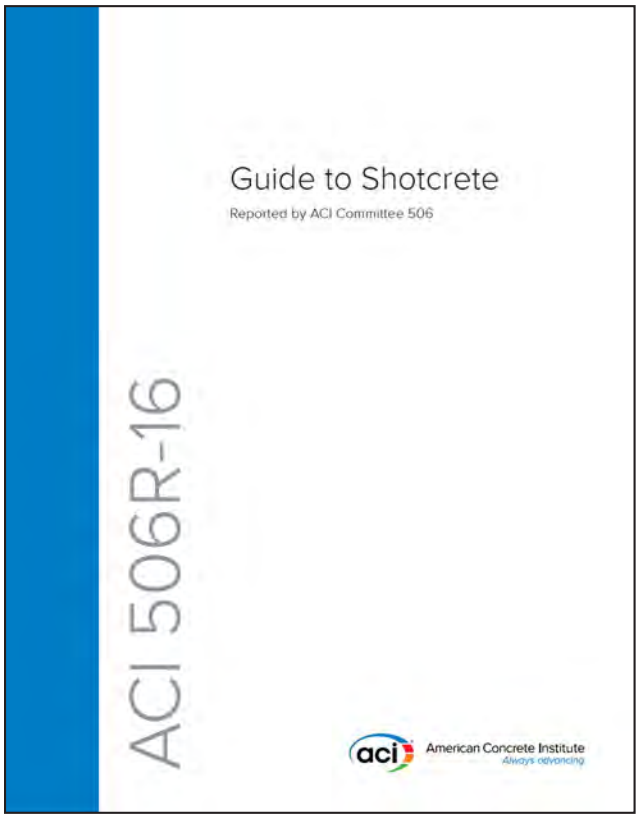
- ACI 301 Specifications for Concrete Construction
- ACI 350.5 Specifications for Environmental Concrete Structures
- ACI 506.2 Specification for Shotcrete
- ACI SPEC-563 Specifications for Repair of Concrete in Buildings

ACI construction specifications include requirements for the contractor's performance on a project. However, they are intended to be used by engineers in developing their construction documents for specific projects. ACI 301 states, "This is a Reference Specification that the Architect/Engineer can apply to any construction project involving structural concrete by citing it in the Project Specifications. A mandatory requirements checklist and an optional requirements checklist are provided to assist the Architect/

Engineer in supplementing the provisions of this Specification as required or needed by designating or specify ingindividual project requirements."

ACI GUIDES & REPORTS

As described in the ACI TCM, "ACI guides are written in non-mandatory language and present committee recommendations for analysis, design, specifying, selection, evaluation, testing, construction, or repair of concrete materials or structures." If a document does not give recommendations from the developing committee, the document will not be titled as an ACI guide. ACI guide types include handbooks, manuals, and TechNotes. Guides can also be used to provide examples, case studies, explain concepts and indicate advantages and disadvantages of various alternatives.



ACI reports are documents on concrete technology within a committee's area of expertise. Reports can cover broader topics such as research results, design or construction methods, or current knowledge on a particular concrete technology.

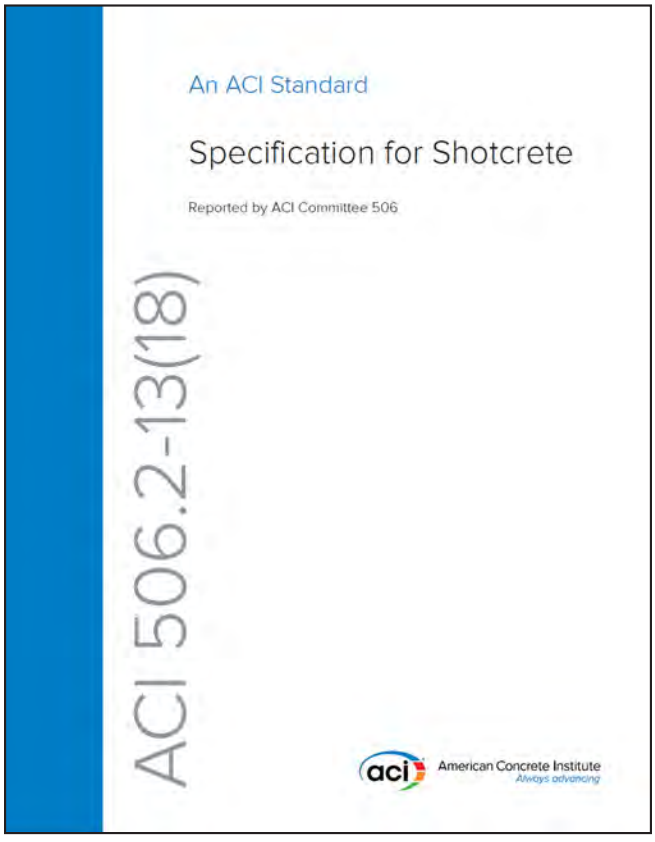
Reports and guides are not required to address a specific user of the concrete construction team, but often serve as an informational resource for information on a given topic.

APPLICATION AND USE

In a given location, building construction is usually governed by building authorities. The local building authority will adopt ordinances to establish minimum requirements that must be met in the construction and maintenance of buildings. The building code is intended to protect the public's health, safety, and welfare. Most building codes review and adopt all or portions of specialty codes that are developed and maintained by industry experts. The International Building Code (IBC) is developed for state and local building authorities to adopt. The IBC in turn references ACI 318 for concrete building structural design.

Engineers use codes to develop structural designs. Specifications are contractual documents directing the construction team, producers and testing agencies on what the owner wants through the engineer. Guides and reports help both the engineer and contractor to understand some aspect of concrete. For example, regarding concrete materials, specifications specify certain qualities and give guidance to both engineers and contractors.

In the early days of shotcrete documents within ACI only the 1966 ACI standard, "Recommended Practice for Concreting (ACI 506-66)" provided any guidance. For years many project specifications that used shotcrete, in error, specified that the shotcrete is to be placed in accordance with, "ACI 506-66 Recommended Practice." The recommended practice was in essence a "Guide" and did not use mandatory language. Many disputes arose due to the non-mandatory language (the recommended practice) being adopted in the mandatory language project specification. In 1977, to provide the engineer with a reference document on shotcrete they could include in their project documents, ACI adopted as a standard, the "Specification for Material, Proportioning and Application of Shotcrete (ACI 506.2-77)."



Unfortunately, today there are still instances where a mandatory project specification references, in error, nonmandatory guide or report documents. Referencing non-mandatory language in a mandatory language document basically makes the mandatory document less enforceable when a dispute arises.

An example of the difference between codes and specifications is a comparison between ACI 318 and ACI 301. ACI 318 gives the designer requirements for designing structural concrete. It is not intended for the contractor to read or interpret for building a project. ACI 301 directs the contractor on how to execute their work on a project. For example, how to properly mix, place and finish concrete. Both codes and specifications use enforceable terms like "shall and must." In comparison, guides and reports use nonmandatory language such as "should or may."

In summary, ACI documents are written for designing, building, evaluating, and repairing concrete structures. Many have a specific target audience, like the designer or the contractor. In taking a structural concrete project from concept to design and concrete in place requires many documents that different members of the project team use. Just remember in broad terms: Code = Engineer, Specification = Contractor, and Guides & Reports = General Information.

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THE USE OF SHOTCRETE AS A REPAIR PROCESS FOR STRUCTURAL CONCRETE REPAIR

By Kevin Robertson

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The shotcrete process has been around since its inventor, Carl Akeley, first came up with the idea of pneumatically conveying a cementitious mortar over 100 years ago. While it has been regarded by many simply as another method of placing concrete, the shotcrete process in the context of concrete rehabilitation is much more than that. The benefits derived from modern shotcrete technology have provided forward-thinking contractors with an economic advantage over their competitors, and specifiers have also recognized that the shotcrete process can provide a durable, long-term repair solution that other repair procedures simply can't match.

To understand the true benefits of the shotcrete process, it is important to first understand what shotcrete is. As defined in ACI 506R, "Guide to Shotcrete,"[1] shotcrete is "Mortar or concrete pneumatically projected at high velocity onto a surface." In other words, shotcrete is not a product; it should be considered a process for placing concrete. So, when evaluating the benefits of a concrete repair, the same properties should apply to a repair whether the repair material is hand-troweled, cast-in-place, or applied at high velocity using the shotcrete process (Fig. 1).

Fig. 1: Concrete (shotcrete) pneumatically projected at high velocity to repair area

DRY VERSUS WET

There are two distinct processes when placing shotcrete. Using the dry process, concrete is conveyed through a hose in an air stream at high velocity. Water is added at the nozzle to produce plastic material on impact. Mixing of water and the dry material occurs at the nozzle and on the receiving surface. Using the wet process, concrete is pumped through a hose and air is added at the nozzle to accelerate the mixture to a high velocity. The key common ingredient for both processes is "velocity." Without high velocity, usually measured at 100 ft (30 m) per second, a pneumatically placed concrete or mortar cannot be described as shotcrete. Compaction achieved when concrete hits a surface at high velocity provides many of the key properties that make the shotcrete process unique as a concrete placement procedure.

When selecting a shotcrete process for a concrete rehabilitation project, it is usually best to leave that decision up to the contractor. Both wet- and dry-process shotcrete can be equally effective; however, some contractors are better suited (because of crew experience, equipment options, access to material, or other factors) to successfully complete a shotcrete repair using one process over the other (Fig. 2).

ENVIRONMENTAL CONDITIONS

Cold-Weather Application: Shotcrete specifications should outline limitations for the placement of shotcrete under varying environmental conditions. When faced with cold temperature conditions, it is best practice to follow the recommendations in ACI 306R, "Guide to Cold Weather Concreting."[2] In addition, the following precautions should be considered:

- Do not apply shotcrete if air temperature is 40°F (4.4°C) and falling unless protective measures taken;
- Do not apply shotcrete on frozen surfaces;
- Keep mixture temperature above 50°F (10°C);
- Protect shotcrete from freezing until it has reached at least 500 psi (3.4 MPa) in compressive strength; and
- Use warm mix water.

The use of concrete mixtures with high early cement and/or accelerators can also expand cold temperature parameters; however, approval should first be obtained from the project engineer. It is also important to note that accelerators should always be added using controlled dosing methods. Too much accelerator can be detrimental to the quality of the concrete.

Hot-Weather Application: When faced with hot temperature conditions, it is best practice to follow the recommendations in ACI 305R, "Guide to Hot Weather Concreting."[3] In addition, the following precautions should be considered:

- Keep shotcrete mixture temperature as low as possible;
- Do not apply shotcrete when ambient temperature exceeds 100°F (38°C) unless precautions are taken;
- Use cool water in mixture;
- Use shades where possible; and
- Use fogging/misting for cooling and controlling evaporation.

SURFACE PREPARATION AND BOND

Understanding that structural designs require the existing concrete and repair material to perform as a single element, the bond between these two components becomes critical. Without a durable bond interface between the existing substrate and the new concrete, a concrete repair can be subject to a high degree of failure.

A strong, durable bond starts with proper surface preparation. After removal of loose and deteriorated concrete, the resultant sound concrete surface should be pre-wetted using a high-pressure water spray (Fig. 3), leaving a saturated surface-dry surface. Free-standing water should not be left on the surface because excess water will create a higher water-cementitious materials ratio (w/cm) in the shotcrete mixture and result in a reduction in bond strength at the interface between the shotcrete and the existing concrete.[4]

Testing has indicated that in a concrete repair application, the shotcrete process often achieves a stronger and more durable bond than other placement methods.[5] This is due to the principles of the shotcrete process and lead back to the previous statement referencing the importance of velocity. In the case of both wet- and dry-process shotcrete, bond quality can be attributed to the high energy transfer that occurs when the shotcrete material impacts the existing concrete surface.

As the stream of plastic concrete initially makes contact with the surface at high velocity, much of the fine and coarse aggregate bounce away from it as "rebound," leaving an accumulation of fine cement paste. As the layer of cement paste builds, fine and coarse aggregates embed into the cement paste and the amount of rebound material is reduced. This layer of cement paste acts as a bonding agent for the shotcrete material, and even without the use of traditional bonding agents, direct tensile bond strengths of shotcrete repairs can generally reach 200 psi (1.4 MPa).[6]

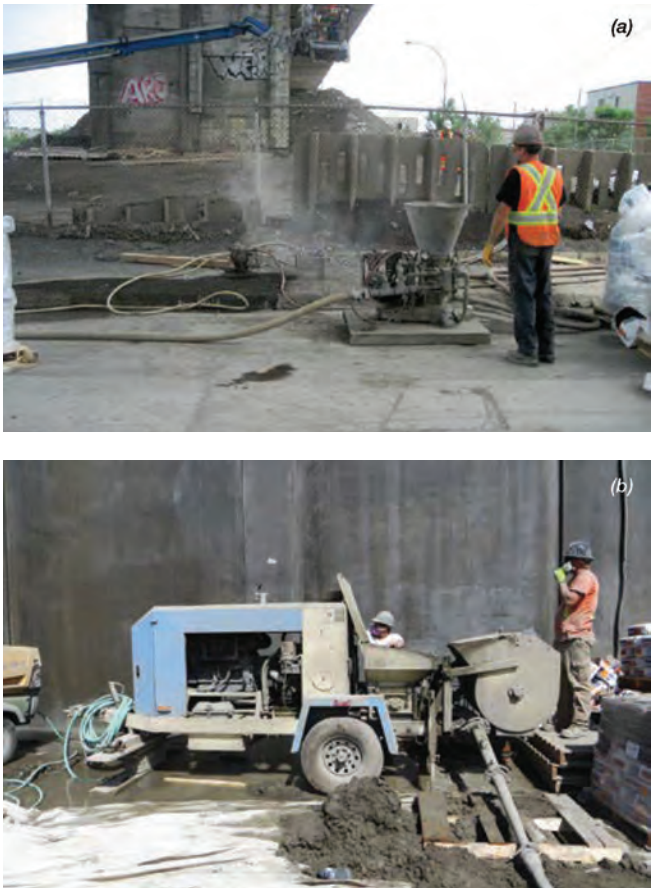

Fig. 2: (a) Dry process shotcrete gun versus (b) wet process shotcrete pump

Fig. 3: High-pressure cleaning of the prepared concrete substrate prior to shotcrete application

Fig. 4: (a)Silica fume; (b) coarse aggregate; and (c) fine aggregate

It has been stated many times by shotcrete experts around the globe that bonding agents are NOT required when concrete is placed using the shotcrete process.[7] Bonding agents interfere with the shotcrete's natural bonding mechanism and often create an unreliable and unpredictable bond, or bond breaker.

SHOTCRETE MATERIALS AND MIXTURE DESIGN

The plastic and hardened properties that are essential for a conventional concrete mixture design also apply to the shotcrete process. For example, air entrainment may not be critical when the concrete is exposed to an environment with little or no freezing-and-thawing exposure, such as Arizona, but if the concrete is used to repair a bridge in the northeast, where exposure to freezing-and-thawing conditions and road salt is prevalent, air entrainment is extremely important.

As in conventional cast-in-place concrete, almost all cement types, admixtures, and types of fiber can be used in shotcrete mixtures. A shotcrete mixture design should be developed to meet the required properties of the project. Hardened property testing should be conducted on core samples, representative of the in-place shotcrete, extracted from the repaired structure or test panels.

Air Entrainment: In areas where exposure to deicing salts and freezing-and-thawing cycles is a concern, the most important performance durability criteria is the air-void spacing factor per ASTM C457/C457M, "Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete."[8] In-place hardened shotcrete, whether applied by the dry or wet process, requires an average air-void spacing factor of under 0.0118 in. (300 mm), with no individual results over 0.0125 in. (320 mm).[9]

In a wet-mix shotcrete application, air content can be measured in two ways: the "as-batched" air content, which is measured at the concrete truck, and the "as-shot" air content, in which the shotcrete material is collected after shooting and measured in an air meter. An air-entrained wet-process shotcrete mixture design will typically have an acceptable as-batched air content of 7 to 10% and an as-shot air content of about 3 to 5%. These air content values will generally provide good durability performance in areas exposed to freeze-thaw conditions and deicing salts.

In a dry-mix shotcrete application, air-entraining admixture should be added in powdered form and pre-blended with other components in prepackaged materials. The shotcrete material manufacturer should have a proven track record producing prepackaged, air-entrained, dry-mix shotcrete and should be able to provide ASTM C457 test data that reflects the recommended air-void spacing factor for dry-mix shotcrete. For the dry process using bulk materials, the addition of an air-entraining admixture is not recommended due to variability in dosage, which can affect strength and durability.

Typically, for the dry process, air content is not tested with an air meter due to the stiffness of the material as shot. The air meter reading is not representative of the air content. The only accurate procedure to evaluate the air content is on a hardened shotcrete sample with the ASTM C457 test method. For both dry and wet processes, the air content on a hardened sample should generally be 4 to 8%.

Silica Fume: Silica fume is a highly pozzolanic admixture (Fig. 4(a)) that improves both the plastic and hardened properties of concrete placed using the shotcrete process. In markets where silica fume is readily available, it is commonly used to improve the shooting characteristics. The use of silica fume in shotcrete will increase adhesion to the bonding surface and cohesion within the shotcrete, consequently allowing thicker placement of shotcrete before sloughing (especially in overhead applications). Although there is no standard test method to measure attainable thickness in one pass, testing has proven that the addition of silica fume has been beneficial in overhead and vertical repair applications.[10]

In terms of hardened concrete properties, silica fume provides increased concrete compressive strength and decreased permeability, which improves resistance to aggressive chemical attack and reduces the potential for chlorides to migrate into the concrete and accelerate the corrosion of reinforcing steel. In areas where exposure to chlorides is prevalent (areas with exposure to deicing salt or seaside areas exposed to salt water), silica fume can improve the durability of concrete repairs.

Aggregates: Appropriate aggregate selection and specifications are often the neglected aspects of the shotcrete mixture design. Generally, specifiers tend to rely solely on ACI 506R, and use either the recommended Gradation #1 or Gradation #2 for combined aggregates (Fig. 4(b) and (c)). However, to ensure optimum durability, including resistance to freeze-thaw conditions and alkali aggregate reaction, concrete aggregates should meet the minimum requirements outlined in ASTM C33/C33M, "Standard Specification for Concrete Aggregates."[11]

When addressing aggregate gradation in a concrete repair application, thickness of the repair will influence the selection of the ACI 506R gradation.

The minimum thickness of a shotcrete application should always be a minimum of three times the maximum diameter of the largest aggregate. Taking into consideration that a shotcrete mixture containing a nominal maximum aggregate

size of 3/8 in. (12.7 mm) in length, the minimum thickness at which the shotcrete mixture should be placed is 1-1/2 in. (38 mm). The use of larger-sized aggregates in shotcrete will also promote an in-place composition as close as possible to that of cast-in-place concrete.[12] This compatibility (between the repair material and the existing concrete) is a crucial factor in achieving a long-term durable repair.

The use of larger coarse aggregate in shotcrete will also have a positive effect on the shootability of a shotcrete mixture. In the case of dry-process shotcrete, it has been proven that the transportation of dry material through a shotcrete hose is more efficient when the mixture contains coarse aggregates. This efficiency can be attributed to the "cleaning effect" that coarse aggregates provide when traveling through the hose. The abrasion of coarse aggregate against the inside lining of the hose reduces the cement buildup and improves material flow. Accordingly, a coarser aggregate gradation will allow the use of longer transportation hoses and reduce plugging.

CURING

Curing is critical, especially for concrete repair applications where the repair areas are often thin and exposed to rapid evaporation. Curing will promote the hydration process to optimize hardened concrete properties and improve durability. Proper curing will ensure that the potential for plastic and drying shrinkage will be reduced.

After finishing operations, the fresh concrete is sensitive and must be protected from surface evaporation. It is important to reduce the time delay between finishing and curing operations. Therefore, the curing program should be available and ready prior to shotcreting. In some critical areas exposed to high heat and wind, fogging could be necessary during the finishing operation and prior to curing.

Vertical surfaces, and other non-overhead shotcrete surfaces, should be wet cured using white synthetic fiber burlap, saturated with water, and covered with a polyethylene plastic sheet to avoid surface evaporation (Fig. 5).

Fig. 5: Wet curing must be continuous for a minimum period of 7 days.

Overhead shotcrete surfaces should be cured using a curing compound that complies with ASTM C309, "Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete."[13] The application rate must comply with the manufacturer's recommendations and form a continuous surface film thick enough to protect the entire surface exposed.

QUALITY CONTROL/QUALITY ASSURANCE

For shotcrete repair applications, the primary goal of a QC/QA program is to assure and verify that the in-place shotcrete achieves the minimum hardened properties outlined in the project specifications. The type and extent of the QC/QA testing required will vary depending on the shotcrete process (wet versus dry).

For wet-mix shotcrete placement, testing of the fresh concrete material after batching is a simple process that follows the same testing requirements as cast-in-place concrete. Testing criteria for plastic properties include slump, air content, unit weight, and temperature. Hardened property testing such as compressive and flexural strength, rapid chloride permeability, and air-void system analysis would be completed in a laboratory environment using cores extracted from the repaired structure or test panels.

For dry-mix shotcrete, the nature of the process eliminates the need to conduct plastic property testing. As in wet-mix testing, hardened property testing would be completed in a laboratory environment, also using cores taken from the repaired structure or test panels.

Fig. 6: Preconstruction testing of shotcrete using a test panel

Preconstruction Testing: Preconstruction test panels (Fig. 6) remain an option for projects with heavy, congested reinforcing steel, or for architectural "mockups" to verify shotcrete color and surface finishes. For projects with significant reinforcing steel, test panels should be fabricated to mirror the types of congestion and sizes of reinforcing steel that are to be encountered during the shotcrete process. For test panels to accurately reflect each situation, the actual shotcrete mixture design, equipment, and nozzlemen should be used.

Nozzlemen Certification and Contractor Qualification: One of the most critical tools to ensure a high level of quality on any shotcrete project is to specify that the nozzleman has obtained ACI certification. While ACI certification verifies that the nozzleman understands the basic theory of shotcrete placement and has demonstrated the skills required to satisfactorily place shotcrete, it does not unilaterally guarantee success.

Nozzlemen certification is only one part of the equation. An equally important aspect of the shotcrete process is the qualification of the contractor. A qualified contractor who specializes in shotcrete placement will typically have certified nozzlemen, a successful track record, equipment, crew, management capabilities, bonding capacity, and verified references that set him or her apart from less experienced, less qualified contractors.

To ensure a shotcrete contractor is qualified to bid and execute a contract involving shotcrete placement, the following checklist can be used as a guide:

- Verify the contractor has a long and successful business history (check references);
- Verify the contractor has successful history on similar projects (check references);
- Ask for work history of the contractor's key personnel (nozzlemen and supervisors); and
- Verify that all nozzlemen are certified for the method (dry and/or wet) and orientation (vertical and/or overhead) for which they will be shooting (verification can be obtained through ACI at **www.acicertification.org/verify**).

CONCLUSIONS

In most cases, the most challenging and successful shotcrete projects begin with a successful specification and continue with a committed team consisting of a knowledgeable engineer, an experienced shotcrete contractor, and a qualified material supplier. Examples of successful concrete rehabilitation projects involving shotcrete placement are plentiful and can be found across North America. Refer to a recent article published in *Shotcrete* magazine[14] regarding the repair of a 60+ year-old dam and power station where the shotcrete process was successfully used in a marine environment.

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U.S. Shotcrete Standards Update

By Charles Hanskat

It's been over nine years since we last updated our reference list of shotcrete related standards and specifications. In that time, we've seen a significant increase in activity by various standards developing organizations in creating new documents incorporating shotcrete and updating their existing documents. Perhaps most exciting is the direct coverage of shotcrete in current versions of ACI 318 and ACI 301, as well as the repair specification ACI 563. Readers are requested to contact the editor and author if inaccuracies are found in the following report, if additional activities should be reported, or if new activities should be initiated.

AMERICAN CONCRETE INSTITUTE (ACI) (WWW.CONCRETE.ORG)

ACI Committee 506 Shotcrete Documents

First note that ACI has changed the style they use for naming documents. For Guides and Reports rather than using "R" following the document number they now use "PRC" preceding the number. Examples of the changes include: The ACI 506R-16 *Guide to Shotcrete* is now ACI PRC-506-16 *Guide to Shotcrete*; ACI 318-19 *Building Code Requirements for Structural Concrete* is now ACI CODE-318-19 *Building Code Requirements for Structural Concrete*; and ACI 506.2 *Specification for Shotcrete (Reapproved 2018)* is now ACI SPEC-506.2-13 *Specification for Shotcrete (Reapproved 2018)*. Thus, all non-mandatory documents, like guides, reports, technotes are PRC. Codes use CODE and construction specifications use SPEC in the title. We've used the new terminology below.

ACI Committee 506, Shotcreting, is currently chaired by Simon Reny and James Ragland serves as Secretary. Many of the recent document updates by the ACI 506 committee were accomplished under the leadership of Marc Jolin as chair. The committee is divided into subcommittees and task groups, each concerned with a specific document or issue. The subcommittees are working on:

- ACI SPEC-506.2-13 *Specification for Shotcrete* (Reapproved 2018) — The shotcrete specification has been completely revised from the previous ACI 506.2-95 version. It includes updated ASTM references including the shotcrete-specific ASTMs that were developed after 1995. It brings in requirements for ACI certified nozzlemen for structural shotcrete applications, submittal of contractor experience for structural shotcrete, and eliminated the core "grading" section that was unevenly applied in practice.
- ACI PRC-506-16 *Guide to Shotcrete* — As the Guide is a non-mandatory document and serves as a "primer" on shotcrete for the industry. The ACI 506 committee also restructured the 506 Guide to align with the specification sections so that the Guide could serve as a commentary for the specification requirements. Content has been added to explain more current technologies. Also added is a more thorough description on why shotcrete doesn't have cold joints when placed in multiple layers.

  NOTE: If looking to purchase both the Specification and Guide, ACI bundles the two together for a reduced price. The package is called "Shotcrete Package - ACI 506R-16 and 506.2-13(18)."
- ACI PRC-506.1-21 *Fiber-Reinforced Shotcrete – Guide* — The previous 2008 version has been updated with revised references and updated technologies. As fiber-reinforced shotcrete is used extensively in underground applications several sections specifically address its use underground. It is a comprehensive document covering materials, production, testing, applications, design considerations and specification.
- ACI PRC-506.4-19 *Guide for the Evaluation of Shotcrete* — The document has had major updates since the 1994 version that was reapproved in 2004. Contents and references have been revised to include current technologies. Also added are new sections on "Acceptance of Shotcrete", "Preconstruction Testing", and "Evaluation of In-Place Shotcrete" and Appendix A "Quality Assurance Flowchart."
- ACI PRC-506.5-09: *Guide for Specifying Underground Shotcrete* —This document serves as a guide to engineers

and owners who are specifying shotcrete for underground applications. It is not a construction specification geared towards the contractor like ACI SPEC 506.2 that can be directly incorporated into contract documents for a specific project, but serves to provide the specifier guidance on what is needed in their particular project specification. This format of a guide specification is rather unique among ACI documents as it is a non-mandatory document that gives guidance on what a specifier may include in their mandatory language contract documents.

- ACI PRC-506.6-17: *TechNote: Visual Shotcrete Core Quality Evaluation* — This is the first Tech Note from ACI 506. It provides a reference for visual evaluation of shotcrete quality using cores. This is intended to assist the engineer or inspector on what level imperfections are acceptable when evaluating cores taken from mockup preconstruction panels, or from in-place work being evaluated. It establishes four categories of visual evaluation of core quality. Of note, Table 1 from the TechNote lists quantitative criteria for each category of core quality that can be referenced during the core evaluation.

ASA members continue to play a significant role in the leadership and work of ACI Committee 506 and its many subcommittees. The committee Chairs are always looking for new members to join and actively participate in developing and maintaining the committee documents.
It should be noted that the only ACI Committee 506 document mentioned that can be directly incorporated by reference into project specifications is ACI SPEC-506.2-13. If portions of any of the other documents are appropriate for the project specification, the applicable language should be put into mandatory language and inserted by the specifier into the project specification. ACI Committees 506 and C660 and subcommittees will meet in October during the Fall 2022 ACI Convention.

ACI Certification Documents for Shotcrete

ACI Certification Committee C660 for Shotcrete Nozzleman Certification maintains the ACI nozzleman certification policies and develops the craftsman workbook for shotcrete nozzleman that is used as the reference document for nozzlemen taking the ACI written exam for shotcrete nozzleman certification.

- ACI CCS-4(20) *Shotcrete for the Craftsman* — This is the technical content for the shotcrete nozzleman. It is updated by the C660 committee and rolled into the CP-60 Workbook. Currently only available in English, but a Spanish version should be forthcoming.
- ACI CP-60(15) *Craftsman Workbook for ACI Certification of Shotcrete Nozzleman* — Both English and Spanish versions of CP-60(15) are available from ACI and updated by the C660 committee periodically. It includes the information from CCS-04 as well as information describing the certification sessions and exams. When both English and Spanish versions of CCS-4 are available the CP-60 will be revised with the current content.
- ACI CP-61PACK - *Shotcrete Inspector Reference Package* — This is a compilation of many ACI documents applicable to both concrete and shotcrete. The CP-61 includes the reference documents that the ACI Shotcrete Inspector certification open-book exam uses for testing the inspector's shotcrete knowledge. [Note: Look at the Executive Director Update in this issue for a more detailed look at the shotcrete inspector education and certification.]

Other ACI Codes and Specifications Including Shotcrete

- ACI CODE 318-19 *Building Code Requirements for Structural Concrete and Commentary* — This is the basis for design of most concrete building structures in the United States as well as many other countries around the world.
- ACI SPEC 301-20 *Specifications for Concrete Construction* — ACI 301 is working to include more aspects of shotcrete directly into the next document. However, to allow ACI 301 to address shotcrete placement the ACI 301 Committee added a mandatory checklist item:

  > 1.1.5 Designate portions of Work to be constructed of shotcrete. Concrete sections not initially designated as shotcrete may be subsequently considered for shotcrete placement after Contractor submittal for consideration. Refer to ACI 506R for guidance on shotcrete. Review ACI 506.2 and ACI 318 and specify requirements for shotcrete.

- ACI CODE 350-20: *Code Requirements for Environmental Engineering Concrete Structures and Commentary* — This is the ACI Code for concrete liquid-containing structures. Shotcrete is addressed in the Code with most provisions oriented to design and construction aspects of wrapped prestressed concrete tanks.
- ACI SPEC 350.5-12 *Specifications for Environmental Concrete Structures* — It is a construction specification similar to ACI 301, but intended for liquid-containing structures rather than buildings. Since shotcrete is widely used in environmental structures it addresses both concrete and shotcrete. As with the Code the main emphasis has been in shotcrete placement for wrapped prestressed tanks.
- ACI SPEC 563-563-18 *Specifications for Repair of Concrete in Buildings* — Similar to the approach by ACI 301, ACI 563 has decided to include shotcrete by referencing ACI SPEC 506.2. The ACI 563 committee included Section 10:

  > SECTION 10—*SPECIFICATION FOR SHOTCRETE (ACI 506.2)*
  > *This Specification is incorporated by reference into this Standard and contains the construction requirements for the application of wet-mixture and dry-mixture shotcrete, with and without fibers.*

ASTM INTERNATIONAL (WWW.ASTM.ORG)

ASTM Committee C09, Concrete and Aggregates, continues its work on specifications and test methods for shotcrete. The C09.46 subcommittee is responsible for the following standards:

- ASTM C1140/C1140M-11 (2019) *Practice for Preparing and Testing Specimens from Shotcrete Test Panels* – The document is current and not under active revision.
- ASTM C1141/C1141M-15 *Specification for Admixtures for Shotcrete* — The document is currently being considered by the committee for revision.
- ASTM C1385/C1385M-10 *Practice for Sampling Materials for Shotcrete* — The document is current.
- ASTM C1436 (Withdrawn 2022), "Specification for Materials for Shotcrete" - The document was not revised and was withdrawn. The 2013 version is available from ASTM. This standard basically served as a vehicle to reference the ASTM standards for standard concrete materials: cement, aggregates, water, and fibers. There is a reference to shotcrete admixtures standard (C1141). The only aspect that was shotcrete specific here, was Table 1, which provided grading limits for combined aggregate for shotcrete. However, this is the same table referenced as Table 1.1.1, currently found in ACI PRC 506 – Guide. Also, in many ways Note 1 in the ASTM standard allowed producers to provide a graded aggregate "within reasonable tolerances" from the average, so the Table values have limited enforceability.
- ASTM C1480/C1480M (Withdrawn 2021), "Specification for Packaged, Pre-blended, Dry, Combined Materials for Use in Wet or Dry Shotcrete Applications" – After polling the committee, all manufacturers indicated they do not use the standard. Thus, there was no need to revise, and it was withdrawn in 2021.
- ASTM C 1604/C 1604M-05 (2012), "Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete"— recently reapproved by the committee. Currently being evaluated for revisions by Task Group of Curt White and the author.
- ASTM C1550-20, "Test Method for Flexural Toughness of Fiber- Reinforced Concrete (Using Centrally Loaded Round Panel)"— Because this test method has been used primarily to characterize fiber-reinforced shotcrete to date, there is continuing interest by ASTM Sub- committee C09.46, ACI Committee 506, and ASA members. This test method is current.
- ASTM C1609/C1609M-19a, "Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)" – This is another fiber-reinforced test standard often used in the shotcrete industry. It is current with ASTM.

INTERNATIONAL CONCRETE REPAIR INSTITUTE (WWW.ICRI.ORG)

The International Concrete Institute is the association representing the concrete repair industry in the United States and Canada. They have a number of technical committees that develop technical documents for concrete repair. Since shotcrete is often used in repair it has been a part of some previous documents, but recently we've made good strides in getting more broad coverage in other ICRI documents. Currently Committee 110 – Specifications and Committee 320 – Concrete Repair Materials and Methods has been the primary focus from a shotcrete perspective.

- ICRI 320.1R-2019 *Guideline for Selecting Application Methods for the Repair of Concrete Surfaces* — This document has included shotcrete previously, but the pneumatically applied mortar section was updated to separate high-velocity shotcrete from low velocity sprayed mortar. Overall, the non-mandatory document illustrates and describes application methods commonly used for placement of concrete repair materials, along with material requirements, appropriate applications, and cautions and limitations for each. In addition, engineering considerations, surface preparation, constructability, environmental factors, quality assurance/control, and safety are addressed.
- ICRI 320.5R-2014 *Pictorial Atlas of Concrete Repair Equipment* — The current document is being revised to include dry-mix and wet-mix equipment. Hopefully the updated version will be available in 2023. The document was developed to provide a single-source common guide that can be used in the trade when describing and specifying concrete repair tools and equipment.
- ICRI 110.1-2016 *Guide Specifications for Structural Concrete Repair* — The initial 2016 guide specification did not include shotcrete placement for repairs. The ICRI 110 committee is nearing completion of an update that will directly include shotcrete. Hopefully this will be available in late 2022 or early 2023. Overall the document is developed to provide a methodology for standardizing the essential requirements for structural concrete repairs by

providing specification text, optional requirements, and commentary to allow the user to tailor the document to a specific concrete repair project, and use as a technical specification section in a complete project manual.

AMERICAN RAILWAY ENGINEERING AND MAINTENANCE-OF-WAY ASSOCIATION (WWW.AREMA.ORG)

The American Railway Engineering and Maintenance-of-Way Association (AREMA) was formed in 1997, by the merger of three engineering support associations, namely the American Railway Bridge and Building Association, the American Railway Engineering Association and the Roadmaster's and Maintenance of Way Association.

- AREMA *Manual for Railway Engineering* (Updated annually)

Committee 8 – Concrete developed and maintains Chapter 8 of the *Manual for Railway Engineering*. This chapter covers concrete materials, design and placement for the wide variety of concrete structures used in the railroad industry. Chapter 8 provisions for shotcrete have been substantially updated to match the current industry standards for shotcrete materials and placement.

AMERICAN SHOTCRETE ASSOCIATION (WWW.SHOTCRETE.ORG)

- *ASA Safety Guidelines for Shotcrete* Though ASA is not a standards developing organization (SDO) we have developed a publication for shotcrete safety. With the input of our members' expertise in shotcrete placement we created this document to provide contractors with a basic set of guidelines for shotcrete safety. It is hoped that shotcrete contractors developing their site-specific safety plans will find these guidelines a good starting point.
- *ASA Website Resources* — On our website **www.Shotcrete.org/Resources** you will find position statements from our Board, Pool and Recreational Committee and Underground Committee on topics dealing with quality shotcrete construction. You will also find links to other industry information including specification resources, conference proceedings, web sessions and other industry links.
- *ASA Technical Questions and Answers* — You may also find valuable information searching our searchable technical questions and answers webpage under the "Product/Services & Information" tab on our home page.
- *ASA Magazine Article Archive Search* — On the **www.shotcrete.org/ArchiveSearch** you can search by keyword(s) to find articles from all our past issues of Shotcrete magazine. With nearly two decades of magazine articles, you can likely find something about nearly any topic within the shotcrete industry.

SUMMARY

The previous 2013 article referenced 17 documents that were eventually published (there were two that were merged into other documents). With this update we delineate 27 standards or guides. Of particular importance is shotcrete being newly covered in ACI 318, 301, 350, 563. This is clear proof that shotcrete is gaining much wider acceptance in all types of codes, specifications, guides and reports. Afterall, shotcrete is a placement method for concrete. However, we can't just sit back as it is a constant challenge to make sure that standard developing organizations like ACI, ASTM, ICRI and AREMA stay abreast of improvements in shotcrete materials, equipment, and placement, and reflect that in their documents.

Charles Hanskat, PE *is a Fellow member of the American Concrete Institute, American Society of Civil Engineers, and the Florida Engineering Society. He is Executive Director and Technical Director for the American Shotcrete Association. He holds a Bachelor's and Master's degree in Civil Engineering from the University of Florida and has been a licensed professional engineer for over 40 years. Hanskat has been involved in the design, construction, evaluation and repair of environmental concrete, marine, building and shotcrete structures throughout his career. Hanskat is active in developing codes and standards from many professional and technical engineering societies including ACI, ASTM, AREMA, and ICRI.*

CORPORATE MEMBER PROFILE

Quikspray® INC.

The story of Quikspray®, Inc. began in the early 1950's when Tom P. McRitchie began building barrel mixers to mix lime putty and plaster for the commercial construction industry. The idea took off, and Tom decided to form an official business. In 1954, he founded Quikstir®, Inc. Each week Tom, the sales manager and major stockholder, traveled to various businesses to demonstrate his mixers. Demand grew and Quikstir® began manufacturing mixers of various sizes and capacity.

Business continued to increase throughout the 1950's & 1960's, along with the need for larger and more powerful mixers. At the same time Tom recognized a need in the industry for the mechanical application (or spraying) of the industrial coatings that his mixers were mixing. So, in 1968, Tom established Quikspray®, Inc. as the manufacturer of these applicators. Initially, Quikspray® began by using technologies such as pressure pot conveyers, vertical piston pumps and progressive cavity screw pumps.

That worked well, until the industry began using larger aggregates and fibers to reinforce their coatings. Tom recognized that a new design was needed to transfer these thicker, heavier materials. The result: the Quikspray® Carrousel® Pump was born. The Carrousel® Pump was a redesigned age-old peristaltic pump. It is now available in 4 different sizes covering a variety of models designed to pump and/or spray most heavy body commercial coatings. The Carrousel® Pump is versatile for contractors needs for pool plaster, rehabilitation & repair, artificial rock and water work, waterproofing, and other commercial coatings.

Today, the Quikstir® and Quikspray® companies remain family owned and operated by the second and third generation of McRitchie's. The mixer line has grown along with the pump line, and a group of broadcasters and applicator guns have been added along with helpful accessory items. Today, Quikspray® and Quikstir® products are marketed and distributed worldwide.

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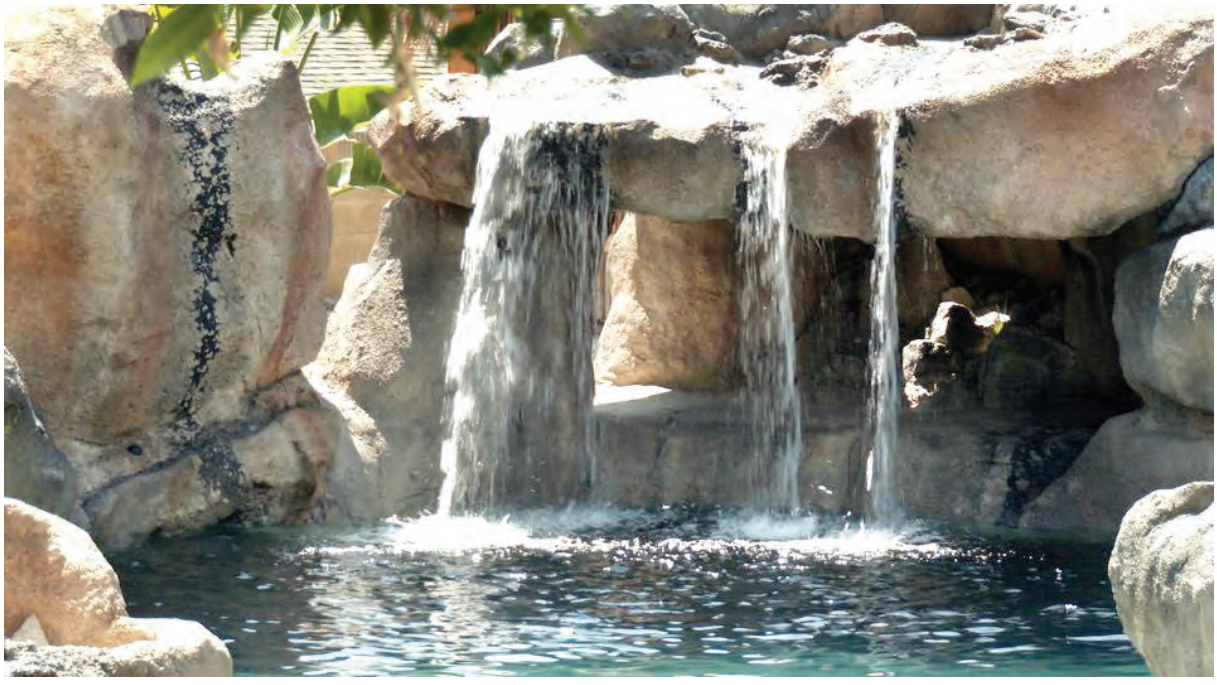

ASA OUTSTANDING SHOTCRETE PROJECT AWARDS PROGRAM

Submit your outstanding project to the 2022 Outstanding Shotcrete Project Awards program! The Outstanding Shotcrete Project Awards features projects from around the world that showcase the innovative use of shotcrete. **Make sure your project is acknowledged as one of the best of the best by submitting an application by Monday, October 3, 2022**. Visit www.shotcrete.org/ProjectAwards for more details and check out the 2021 winners that were recognized at the 17th Annual Outstanding Shotcrete Project Award banquet!

ACI RESOURCE CENTERS - ASA SHOTCRETE INSPECTOR EDUCATION AND ACI CERTIFICATION

Quality Shotcrete – Know It When You See It (Shotcrete Inspector Seminar)

ASA, supporting ACI's Shotcrete Inspector Certification program, presents the seminar designed to help you recognize quality shotcrete for all those involved in inspecting, specifying, or supervising shotcrete projects. This seminar also helps contractors highlight the quality of their work to project owners. Those pursuing Shotcrete Inspector Certification may take the 90-minute ACI certification written exam at the end of the seminar.

September 28, 2022
ACI SoCAL Resource Center
San Bernardino, CA
8:00 AM – 4:30 PM
(followed by optional written exam)


Oscar Duckworth

Oscar Duckworth, owner of Valley Concrete Services, is an ACI Certified Nozzleman with over 25,000 hours of nozzle time. Duckworth currently serves as Treasurer on the American Shotcrete Association's Executive Committee and Chairs ASA's Education and Safety Committee. Duckworth played a contributing role in the development of ASA's Shotcrete Inspector seminar, also known as "Quality Shotcrete – know it when you see it."

October 6, 2022
ACI Resource Center Midwest
Elk Grove Village, IL
8:00 AM – 4:30 PM
(followed by optional written exam)


Charles Hanskat

Charles Hanskat, P.E. is ASA's Executive and Technical Director. He has been involved in the design, construction, and evaluation of environmental concrete and shotcrete structures for over 40 years, bringing his knowledge and expertise to many standards committees for ACI, ASTM, AREMA and ICRI. Hanskat played a contributing role in the development of ASA's Shotcrete Inspector seminar, also known as "Quality Shotcrete – know it when you see it."

ACI FALL NOZZLEMAN CERTIFICATION SESSION

The Shotcrete Guild
October 7 - 9, 2022
Sebastopol, CA

Both Wet- & Dry-Mix processes with Vertical and optionally Overhead certification exams will be offered. This session welcomes nozzlemen-in-training (requiring a minimum of 25 hours of shooting experience), new full certification (requiring a minimum of 500 hours of shooting experience), and recertifying (with either an oral interview or written exam) candidates. Reserve your spot today! For details contact: sirosscar@sonic.net or (415) 378-8178.

ASA 2022 FALL COMMITTEE MEETINGS

ASA will be hosting our Fall committee meetings on Saturday, **October 22, 2022**, at The Westin – Dallas Fort Worth Airport, Dallas, TX. ASA's mission is to provide knowledge resources, qualification, certification, education, and leadership to increase the acceptance, quality, and safe practices of the shotcrete process. This mission is moved forward through the work of the ASA Committees: Education & Safety, Marketing, Membership, Pool & Recreational Shotcrete, Underground, Contractor Qualification, and Technical.

Committee meetings are open to the public and ASA welcomes and encourages the participation of all interested parties in the shotcrete industry. Make plans to attend our upcoming meetings. Go to our website calendar for links to hotel reservations at special discounted rates www.shotcrete.org/calendar.

October 22, 2022, ASA Fall Committee Meetings:

8:00 – 9:00 AM	Contractor Qualification Committee
9:00 – 10:00 AM	Membership Committee
10:15 – 11:15 AM	Marketing Committee
11:15 – 12:15 PM	Education & Safety Committee
1:15 – 2:15 PM	Underground Committee
2:15 – 3:15 PM	Pool & Recreational Committee
3:30 - 5:30 PM	Board of Direction

JOIN OUR SHOTCRETE MAGAZINE ADVERTISERS!

ASA's 2023 Media Kit is now available! Place your 2023 insertion orders by November 1, 2022 for Early Bird discounts! Advertising in Shotcrete magazine will position your company top of mind in the shotcrete industry. Reach the companies and people that you need to grow your business at a competitive price, with an average savings of 25% or more compared to other leading trade association magazines. These rates certainly provide you with the most "bang" for your advertising dollars! Visit **www.shotcrete.org/MediaKit** for more information or contact us info@shotcrete.org to submit your advertisement.

POOL | SPA | PATIO EXPO 2022

Quality Shotcrete – Know It When You See It

November 16, 2022
Las Vegas Convention Center
Las Vegas, NV

Charles Hanskat, ASA Executive Director, will be conducting "Quality Shotcrete – Know It When You See It" with a focus on shotcreted pool shells. Though you may have used shotcrete contractors for years on your projects do you know what to look for to confirm you're getting the best quality for your money? Shotcrete is a placement method for concrete that is fundamentally different from cast-in-place with different equipment, material selection, crew responsibilities, application techniques, testing, curing and protection that need to be considered for producing high-quality and durable shotcrete you as a pool contractor and the owner expect. This ASA seminar provides guidance on

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over 40 critical elements of shotcrete applications for those onsite to properly evaluate the overall quality of shotcrete placement. These include an overview on material selections, equipment, placement techniques, finishing, curing, protection, testing, and safety as it relates to the shotcrete process.

For shotcrete contractors, this seminar will help you verify the quality of your work to your general contractors and inspectors. Optional Reference Resource can be purchased directly from ASA: CP61 Pack is the Reference Resource for the open book exam – for those pursuing ACI Shotcrete Inspector Certification.

WORLD OF CONCRETE 2023

Las Vegas Convention Center
Las Vegas, NV
Separate registration needed for all courses.
Registration will open soon. Visit ASA's booth in the South Hall: S11038

ASA Shotcrete Nozzleman Education Course
Tuesday, January 17, 2023

This course is designed for shotcrete nozzlemen, individuals involved with inspection of shotcrete, and anyone interested in learning about the principles and practices that must be known and understood for a nozzleman to satisfy his role in the quality application of the shotcrete process.

ASA Nozzleman Education Courses present an overview on placement technique, finishing, curing, testing, equipment and safety as it relates to the nozzleman and the shotcrete process. This course also helps to prepare individuals for participation in the ACI Nozzleman Certification program. ACI required work experience, written exam, performance exam and other program criteria will be discussed.

The CP-60(15) Shotcrete Nozzleman Craftsman Workbook is included with the course registration fee.

Recognizing Quality Shotcrete
Wednesday, January 18, 2023
8:00 AM – 4:00 PM (without exam; 6:00 PM with exam)

Contractors, though you may have used shotcrete contractors for years on your projects do you know what to look for to confirm you're getting the best quality for your money? Though shotcrete is a placement method for concrete the process has fundamentally different equipment, material selection, crew responsibilities, application techniques, testing, curing and protection that need to be considered for producing high-quality and durable shotcrete you as a contractor and the owner expect.

This seminar from ASA provides guidance on over 40 critical elements of shotcrete applications for those onsite to properly evaluate the overall quality of shotcrete placement. These include an overview on material selections, equipment, placement techniques, finishing, curing, protection, testing, and safety as it relates to the shotcrete process. For shotcrete contractors, this seminar will help you verify the quality of your work to your general contractors and inspectors.

Optional Reference Resource can be purchased directly from ASA: CP61 Pack is the Reference Resource for the open book exam – for those pursuing ACI Shotcrete Inspector Certification. (https://shotcrete.org/product/cp-61pack-shotcrete-inspector-reference-package/)

ACI Shotcrete Nozzleman Certification
(Wet-Mix Vertical & Overhead)
Thursday & Friday, January 19 - 20, 2023
For New, Nozzlemen-in Training, or Recertifications
(Includes written & vertical performance exams)
Certification Registration (separate registration needed):
www.worldofshotcrete.com

Registration and work experience submission deadline – **January 2, 2023**:

Work experience forms to document hours:
https://shotcrete.org/wp-content/uploads/2021/03/ASA_Work_Experience_Form_2021.pdf

General information on certification:
https://shotcrete.org/education-certification/shotcrete-nozzleman-certification-program/

Work experience hours required:

- Nozzleman-in-training: 25 hours
- New certification: 500 hours
- Recertification with oral interview: 1000 hours within last 2 years
- Recertification with written exam: 0 hours, need proof of certification

Thursday, January 19, 2023 | Hydro-Arch Yard
Henderson, NV | Start time: 8:00 AM
Oral Interviews and Performance panels.

Friday, January 20, 2023 |Location TBD
Henderson, NV | Start time: 8:00 AM
8:00 AM - Written exam will take place at the office
12 noon – Coring begins at the yard

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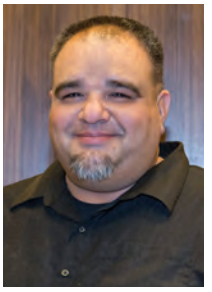

Juanjose Armenta-Aguirre

We are very excited to have Juanjose Armenta-Aguirre join the team. Juanjose, who will be based out of Texas, is a 2nd generation gunite guy and has spent his 20+ year career with his parents' two gunite companies in Central Texas and has extensive hands-on and supervisory experience from a contractor's perspective. The man knows his gunite.

In addition to Juanjose's background in the gunite world, you may know him from his work on several boards, committees, and associations like the American Shotcrete Association (ASA), American Concrete Institute (ACI) and the Pool and Hot Tub Alliance (PHTA). He is now the Gunite Supply & Equipment representative for the Central Region of the United States.

NORMET ACQUIRES ALIVA EQUIPMENT ASSETS TO STRENGTHEN ITS SPRAYED CONCRETE OFFERING

Normet acquires Aliva Equipment assets to strengthen its sprayed concrete offerings.

Normet has entered into an agreement with Sika to acquire its Aliva Equipment business assets. With the acquisition, Normet supports its growth strategy by strengthening its offering in sprayed concrete processes.

"With this acquisition we welcome the prestigious Aliva brand and employees to Normet. We look forward to working together in bringing more comprehensive solutions and services to our combined customer base and strengthening our presence in Central Europe," comments Ed Santamaria, President and CEO of Normet.

"With Normet Group, Sika has found the right strategic owner for the Aliva Equipment business. Normet is specialised in underground construction and will expand investments in the long-term development of the Aliva business, its people, products, and technologies. Being a part of the core business of a global company will open up new opportunities for the strategic development of Aliva and its employees. Customers can continue to rely on the availability of high-quality equipment and support in the future," comments Ivo Schädler, Regional Manager, EMEA of Sika Group.

Founded in 1946, and transferred to the ownership of Sika AG in 1989, Aliva Equipment is one of the world's leading manufacturers of equipment and accessories for the application of sprayed concrete. In addition to classic underground construction, Aliva machines are also used in special civil engineering, on tunnel boring machines, and for the application of refractory material in the steel industry. Aliva Equipment's main operations are in Widen, Switzerland with operations also in Lüdinghausen, Germany and has 50 employees.

Aliva Equipment will be acquired as an assets purchase and will continue to operate under its Aliva brand name from its current locations. The parties have agreed not to disclose any financial details related to the transaction.

For more information, please contact:
Ed Santamaria, President and CEO, Normet Group Oy
Phone: +358 50 4778102
E-mail: Ed.Santamaria@Normet.com

asa Sustaining Corporate Members

Thank you, Sustaining Corporate Members, for your investment in the industry! ASA Sustaining Corporate Members show true dedication to ASA's vision to see "structures built or repaired with the shotcrete process accepted as equal or superior to cast concrete." These industry leaders are recognized for their exemplary level of support for the Association in a variety of ways.

Buesing Corporation
www.buesingcorp.com

CanCrete Equipment Ltd.
www.cancrete.ca

Curtis Concrete Pumping
www.curtisconcretepumping.com

Dees-Hennessey, Inc.
www.deeshenn.com

Maple Site Solutions
www.maplesitesolutions.ca/

Consolidated Shotcrete Inc.
www.consolidatedshotcrete.ca

REED Shotcrete Equipment
www.reedpumps.com

Coastal Gunite Construction Company
www.coastalgunite.com

EdenCrete
www.edencrete.com

Checkered Flag Construction
www.activemember.com/
checkeredflagconcreteconstruct

Construction Forms
www.ConForms.com

MAPEI Underground Technology Team
www.utt-mapei.com

Cost of Wisconsin, Inc.
www.costofwisconsin.com

The Quikrete Companies
www.quikrete.com

Gunnite International (PTY) LTD
www.gunnite.co.za

Sika STM - Shotcrete, Tunneling & Mining (Canada)
www.sika.com

Gulf Shotcrete, LLC
www.gulfshotcrete.com

Baystate Shotcrete, LLC
www.baystateshotcrete.com

Sika STM - Shotcrete, Tunneling & Mining (USA)
www.sika.com

Superior Gunite
www.shotcrete.com

Master Builders
www.master-builders-solutions.com

SHOTCRETE FAQs

As a service to our readers, each issue of *Shotcrete* magazine will include selected questions and provide answers by the American Shotcrete Association (ASA). Questions can be submitted to info@shotcrete.org. Selected FAQs can also be found on the ASA website at www.shotcrete.org/FAQs.

Question: *I am a TBM Tunnel Engineer from India, and I was looking for information on the applicable compressed air pressure range required for a wet-mix shotcrete application (small shotcrete pump-capacity 7 CU.M/Hr) hand spraying with a 30m hose for a better-compacted mix. I would kindly request you to please send me information on the pressure range to be expected for good quality shotcrete placement of the concrete mix on the rock substrate in NATM Tunneling.*

Answer: Wet-mix shotcrete depends on air flow at the nozzle to accelerate the concrete to 60 to 80 mph (100 kph to 130 kph). Most air compressors produce their air flow capacity at 100 to 120 psi (7 to 8.4 kg/cm^2) at the compressor. However, depending on the size length and couplings in the air hose, there may significant pressure drops when the air reaches the nozzle. Here's what ACI 506R-16 Guide to Shotcrete Section 4.4.2 states for wet-mix:

"The recommended ft^3/min (m^3/min) needed for the wet-mix process is between 200 to 400 ft^3/min (5.7 to 11.3 m^3/min) air volume at 100 psi (7 bar). Higher air volume capacities are needed for higher volume and higher-velocity shotcrete applications. If a blowpipe is to be used during the shooting process, more air will be required to run both operations simultaneously. Conducting a test during the preconstruction testing phase using a blowpipe while gunning the wet-mix material will indicate if the air compressor has enough air volume capacity to perform both tasks at the same time. Long, small-diameter lines may not provide sufficient air volume capacity, even with a large air compressor. Test and consider increasing the size of the air line."

Though there is no direct guidance for air pressure at the wet-mix nozzle you may consider the guidance for dry-mix air pressure in ACI 506R Section 4.4.1:

"The operating air volume (ft^3/min [m^3/min]) drives the material from the gun into the hose, and the air pressure is measured at the material outlet or air inlet on the gun. The operating pressure varies directly with the hose length, the density of the material mixture, the height of the nozzle above the gun, and the number of hose bends. Experience has shown that operating pressures should not be less than 60 psi (4 bar) when 100 ft (30 m) or less of material hose is used, and the pressure should be increased 5 psi (0.34 bar) for each additional 50 ft (15 m) of hose and 5 psi (0.34 bar) for each additional 25 ft (7.5 m) the nozzle is above the gun."

The minimum 60 psi (4 bar) necessary for dry-mix could be applied to the wet-mix air supply as the velocity created by the air flow is similar.

Question: *I would like to know the fire rating information on a shotcrete wall, 8 in. thick.*

Answer: Shotcrete is simply a placement method for concrete. Thus, fire resistance of any shotcreted concrete section can be evaluated by consulting ACI CODE-216.1-14(19) Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies. There are many factors that affect the fire resistance so you will need to review the code to establish what's appropriate for your structure.

Question: *Is there a guide to determining pressure applied to a form during shotcrete placement? I have seen references to 50 lb/ft^2 (240 kg/m^2) but no backup to this. Is the ACI formwork design guide applicable to shotcrete in some way?*

Answer: Since shotcrete is pneumatically placed against a one-sided form there is no liquid concrete pressure against the form. When bench shooting vertical walls the majority of pressure from the high velocity impact is carried by the previously placed concrete as the concrete is stacked. Plus, this pressure is very localized, only affecting a small zone immediately adjacent to the impact area of the material stream. Here is an article on a research project that quantified the force https://shotcrete.org/wp-content/uploads/2020/05/2007Sum_TechnicalTip.pdf

From the paper conclusion "In normal spraying conditions, wet- and dry-mix shotcretes produced a force on the panel of about 45 and 20 lb (200 and 90 N), respectively. The maximum load recorded is 87 lb (389 N) and it was observed in simulating a water plug."

If your shotcrete form is exposed to wind forces before placing shotcrete, you may want to consider the wind pressure that may be expected across the entire form during construction to keep the form intact. This should be much less than the 50 lb/ft^2 pressure you mention. ACI formwork design is intended for cast concrete where liquid concrete is contained within a two-sided form and is NOT applicable to shotcrete placement. Some sources show a 60 mi/hr (100 km/hr) wind exerting about 10 lb/ft^2 (50 kg/m^2) on a vertical wall.

Want all the benefits of the Shotcrete process?

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1. Start with a project-appropriate specification
2. Use only QUALIFIED CONTRACTORS with relevant project experience
3. Verify Nozzlemen are ACI Certified

aci

American Concrete Institute

www.concrete.org

www.ACICertification.org/verify
to confirm that the nozzleman on
your job is ACI certified

asa

www.shotcrete.org

SHOTCRETE CALENDAR

Please check with the meeting provider as some meetings may be postponed or cancelled after publication of this issue of Shotcrete.

OCTOBER 6, 2022

Quality Shotcrete – Know It When You See It (Shotcrete Inspector Seminar)
ACI Resource Center Midwest | Elk Grove Village, IL

OCTOBER 7 – 9, 2022

ACI Shotcrete Nozzleman Certification – Wet & Dry-Mix
Valley Concrete Services | Sebastopol, CA

OCTOBER 13, 2022

Architectural Shotcrete – Creative, Sustainable and Durable Concrete Structures using Shotcrete
McCormick Place | Chicago, IL

OCTOBER 13 – 14, 2022

Chicago Build Expo
McCormick Place | Chicago, IL

OCTOBER 22, 2022

ASA Fall Committee Meetings
The Westin – Dallas Fort Worth Airport | Dallas, TX

Time	Meeting
8:00 – 9:00 AM	Contractor Qualification Committee
9:00 – 10:00 AM	Membership Committee
10:00 – 10:15 AM	AM Networking Break
10:15 – 11:15 AM	Marketing Committee
11:15 – 12:15 PM	Education & Safety Committee
12:15 – 1:15 PM	*Lunch*
1:15 – 2:15 PM	Underground Committee
2:15 – 3:15 PM	Pool & Recreational Committee
3:15 – 3:30 PM	PM Networking Break
3:30 – 5:30 PM	Board of Direction

OCTOBER 23 – 27, 2022

ACI Concrete Convention - Fall 2022
Hyatt Regency Dallas | Dallas, TX

NOVEMBER 7 – 9, 2022

ICRI Fall Convention
InterContinental Buckhead Atlanta | 3315 Peachtree Road, NE | Atlanta, GA

NOVEMBER 15 – 18, 2022

International Pool Spa Patio Expo 2022
Las Vegas Convention Center | Las Vegas, NV

NOVEMBER 15, 2022

ASA Shotcrete Nozzleman Education – PSP/Deck Expo 2022
Las Vegas Convention Center | West Hall – W308 | Las Vegas, NV

NOVEMBER 16, 2022

Quality Shotcrete – Know It When You See It – PSP/Deck Expo 2022
Las Vegas Convention Center | West Hall – W308 | Las Vegas, NV

DECEMBER 4 – 7, 2022

ASTM – C09: Concrete & Concrete Aggregates
Sheraton New Orleans Hotel | New Orleans, LA

JANUARY 15 – 18, 2023

6th International Conference on Grouting & Deep Mixing
New Orleans Marriot | New Orleans, LA

JANUARY 16 – 19, 2023

World of Concrete 2023
Las Vegas Convention Center | Las Vegas, NV
Visit ASA Booth: S11038 | www.worldofconcrete.com

JANUARY 17, 2023	**ASA Shotcrete Nozzleman Education** Las Vegas Convention Center | Las Vegas, NV
JANUARY 18, 2023	**Quality Shotcrete - Know It When You See It** Las Vegas Convention Center | Las Vegas, NV
JANUARY 19 – 20, 2023	**ACI Shotcrete Nozzleman Certification** World of Shotcrete | Henderson, NV
JANUARY 24 – 26, 2023	**The Pool & Spa Show 2023** Atlantic City Convention Center | Atlantic City, NJ
FEBRUARY 26, 2023	**Shotcrete Contactor Education** Ojai Valley Inn | Ojai, CA
FEBRUARY 26 – 28, 2023	**ASA 2023 Shotcrete Convention & Technology Conference** Ojai Valley Inn | Ojai, CA
FEBRUARY 26 – 28, 2023	**ASA 2023 Spring Committee Meetings** Ojai Valley Inn | Ojai, CA
FEBRUARY 26 – MARCH 1, 2023	**SME Annual Conference & Expo 2023** The Colorado Convention Center | Denver, CO
MARCH 14 – 18, 2023	**CONEXPO-CON/AGG 2023** Las Vegas Convention Center | Las Vegas. NV
APRIL 2 – 6, 2023	**ACI 2023 Spring Concrete Convention** Hilton San Francisco Union Square | San Francisco, CA
APRIL 17 – 19, 2023	**ICRI 2023 Spring Convention** JW Marriott Parq Vancouver | Vancouver, BC Canada

MORE INFORMATION

To see a full list, current updates, and active links to each event, visit www.shotcrete.org/calendar.

NEW ASA MEMBERS

american shotcrete association | asa

CORPORATE MEMBERS

DMB CONSTRUCTION CORP.
Bayport, NY
WWW.DMB-CONSTRUCTION.COM
Primary Contact: Erin Egan
erinegan@dmb-construction.com

Phoenix Marine Co. DE, LLC
Sayreville, NJ
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Primary Contact: Howard Charles
hcharles@phoenixmarine.com

Genesis/Nspf
Alexandria, VA
genesis.phta.org
Primary Contact: Sheri Jackson
sjackson@phta.org

SUSTAINING CORPORATE ADDITIONAL

Daniel Regad
Sika STM- Shotcrete, Tunneling, & Mining (USA)
Lyndhurst, NJ

INDIVIDUAL

Kristen Melo
Preserve Pools LLC
Summerville, SC

EMPLOYEE OF PUBLIC AUTHORITIES OR AGENCIES

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University of Kentucky, CAER
Lexington, KY

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