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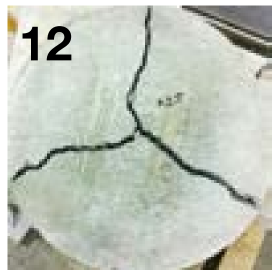
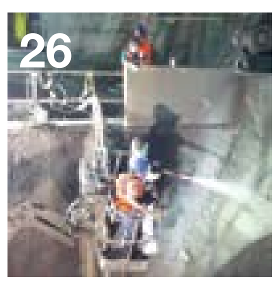
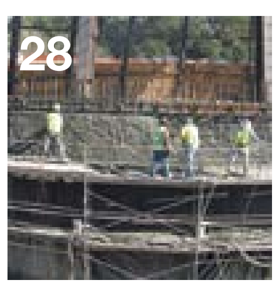
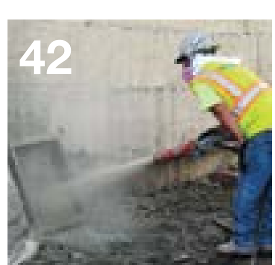
FEATURES









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American Shotcrete Association
38800 Country Club Dr.
Farmington Hills, MI 48331
Phone: 248.848.3780
Fax: 248.848.3740
E-mail: info@shotcrete.org
Website: **www.shotcrete.org**

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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).

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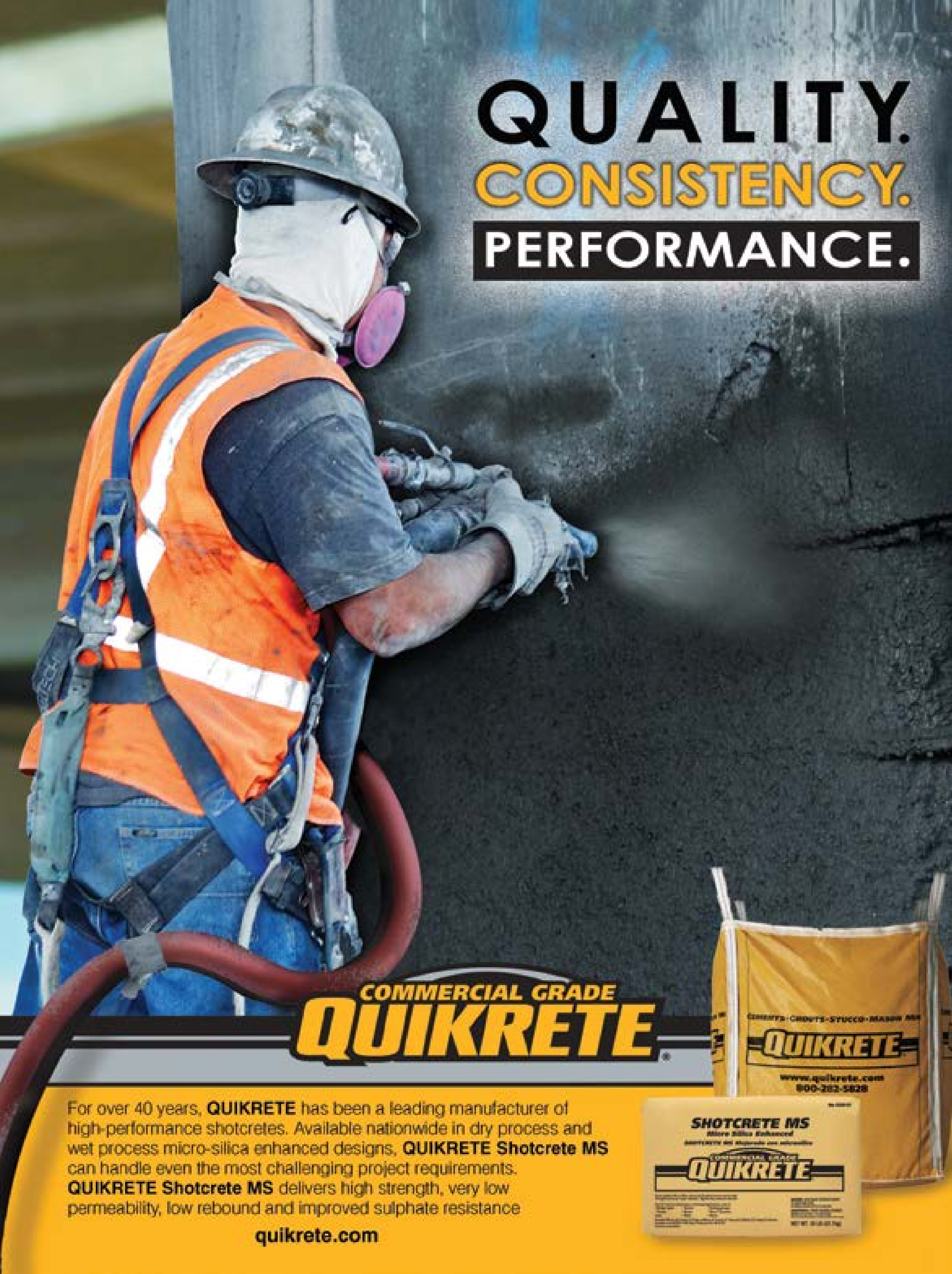
DEPARTMENTS

On the cover: A certified nozzleman and blowpipe operator constructing mockup panels for an enclosure wall. Photo courtesy of Joseph J. Albanese, Inc. Read the article on page 28, reprinted from the December 2019 issue of Concrete International*.*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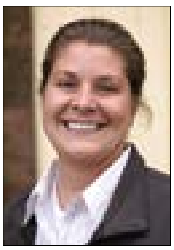
ASA's Commitment to Restore the Reputation of Shotcrete

By Cathy Burkert



It has finally occurred. An ASA Qualified Contractor's worst nightmare. I am sure many of you can relate to this story. We have been doing work for many years for a specific customer and while they always specify the generic concrete repair form-and-pour specification, they have always been open to allow shotcrete as a method of placement. Our state DOT has a very detailed specification for shotcrete using prepackaged material and even has a rule that all overhead repairs must be completed using shotcrete. When we are fortunate to get a job with this specific owner, we always immediately submit an RFI to use shotcrete and include all our credentials, along with the state specification for reference. They have always been very open and typically reply with very timely approval. This specific project, repairing an old station building along the river, is ideal for shotcrete placement—for example, beam repairs on the underside of the basement area in the building, wall repairs, and underside slab repairs over water. As usual, they specified their generic form-and-pour specification and immediately after the contract was awarded, we submitted the use of shotcrete placement. At first it was accepted but they wanted a better procedure for containing debris near the waterway. So, we resubmitted a procedure with a sketch of the proposed containment method. As the demolition phase began, I was concerned about why the resubmittal had not been answered yet. In the meantime, they issued an RFP for pricing on some additional areas. While we waited for an official approval for shotcrete placement, we provided a proposal for the additional areas in the RFP. Then they finally responded… rejected. They cited discontentment with the finish as their reason. What? I was baffled.

At first, I thought maybe the owner's designers were new, and were uneducated about shotcrete, because we all know the wide variety of ways shotcrete can be finished, including as-shot, screeded, smooth, broomed, and even special effects such as rock carving. As we began drafting the response to their rejection, I called the general contractor to see if there was some misinformation being discussed about shotcrete. After a lengthy conversation with him, I told him we would be willing to use the additional area in the RFP as a mockup section for confirming the desired finish, free of charge. In seeing the shotcrete placement and finishing during the mockup, I thought we could address all their concerns about the "finish" and show them the different finishes available. I also mentioned that we would be willing to offer a credit for the contract work if shotcrete would be accepted.

A meeting was held to discuss the shotcrete option on our project. As it turns out, shotcrete was rejected not because of the containment or the finish, but because the owner had recently allowed shotcrete in lieu of form-and-pour on another job installed by a different contractor and was very disappointed in the work. While we pleaded that we are not *that* contractor and shotcrete should only be placed by qualified contractors, they were unyielding in that *shotcrete* as a process was the problem, not the other contractor's shoddy work. I even suggested that they take advantage of ASA's on-site seminar (a complimentary benefit to Sustaining/Corporate members and DOTs), so they could get a better understanding of shotcrete, but again was dismissed. This owner had been burned so bad that they were not willing to consider our offer of a free mockup, credit for contract work, free education, or hear any more of the issue. So, our biggest fear in the industry has occurred. This specific owner was so upset and displeased by poor shotcrete placement from an unqualified contractor that they have decided to outlaw shotcrete indefinitely on all their jobs.

This is just one example of a personal experience. I am sure there are many of you out there that have experienced this same issue. It is tragic that many unqualified contractors are out there performing poor quality work and giving shotcrete as a process a bad reputation. This is exactly why ASA was established over 20 years ago. The vision of ASA is "Structures built or repaired with the shotcrete process are accepted as equal or superior to cast concrete," fueling our mission to "… provide knowledge resources, qualification, certification, education, and leadership to increase the acceptance, quality, and safe practices of the shotcrete process."

Additionally, this is why the ASA Contractors Qualification Program was developed. It helps to establish a shotcrete contractor's qualifications through review of the contractor's work, by the ASA Contractor's Qualification Review committee, whose members have extensive experience in successful shotcrete work. It leverages the reputation of the Association and our experienced members, to review

"It is tragic that many unqualified contractors are out there performing poor quality work and giving shotcrete as a process a bad reputation."

a contractor's ability to successfully perform the caliber of work required, on behalf of the owners and specifiers. Our qualification program provides a distinct service to the industry by assuring specifiers that shotcrete contractors reviewed have a proven record for completion of successful projects of similar work and scope. Specifiers are encouraged to require the ASA Shotcrete Contractor Qualification for their specific projects, selecting the appropriate level of qualification based on the difficulty of application. This program was based on the ASA Board position paper "Shotcrete Contractor and Crew Qualifications."

ASA proudly supports its programs to and strives to educate the industry on shotcrete by offering complimentary on-site seminars. ASA's informational presentations are free to the host organization with five or more architects, engineers, or specifiers in attendance. Webinars connecting multiple locations could also be arranged. The shotcrete process offers numerous quality, durability, efficiency, and sustainability advantages, but proper knowledge of the process is critical to the creation of a quality specification and for the success of any specifier/owner employing the process. Maintaining a high level of quality for concrete placed via the shotcrete method is one of ASA's primary concerns. We have found our on-site presentations to be an excellent tool for all involved. Typically, these are 60-minute presentations, including Q&A, but can be tailored to accommodate your needs. ASA is a registered AIA/CES Provider. ASA also offers the Shotcrete Inspector Education seminar in support of the newly launched ACI Shotcrete Inspector Certification program. More details on the Shotcrete Inspector Education can be found on page 26 of this issue.

In conclusion, ASA offers many resources to contractors, engineers, inspectors, and designers, including many free education programs. It is our commitment to continue to promote and advance shotcrete. Hopefully after some time, we can bring these owners that have been burned by poor quality installation, back to the reality that shotcrete is in fact equal to or superior to form-and-pour concrete when proper materials, equipment, and placement techniques are used by experienced shotcrete contractors.

ASA Underground Committee

By Axel G. Nitschke

My last memo as Chair of the ASA Underground Committee covered the committee's successful completion of the development of a seminar presentation introducing the use of underground shotcrete, titled "Shotcrete for Underground Applications – An Introduction to ACI 506.5R-09 Guide for Specifying Underground." Since then, we have been presenting the topic to owners and interested audiences in engineering and construction companies. Special thanks go out to ASA member Frank Townsend, who is especially active in this regard. If you are interested in hosting this complimentary presentation, which carries AIA LU/PDH credits, I encourage you to reach out to ASA at info@shotcrete.org to have one scheduled.

The ASA Underground Committee continues to be very active and has reached two major milestones by publishing two position statements this year. Position Statement #1, "Spraying Shotcrete Overhead in Underground Applications," and Position Statement #2, "Spraying Shotcrete on Synthetic Sheet Waterproofing Membranes," are available as a free download at **www.shotcrete.org/pages/products-services/shotcrete-resources.htm**. In addition, Position Statement #2 is published in this issue on page 35 and Position Statement #1 was published in the Summer 2019 issue of *Shotcrete* magazine.

Position Statement #1 introduces the basic elements of the adhesion and cohesion of overhead shotcrete, proper application techniques, and a discussion on the "reentry criteria" for working under freshly installed shotcrete. Recommendations, from ASA's perspective, for contractors and owners on how to properly apply shotcrete, as well as on how to specify and inspect overhead shotcrete in underground projects, are included.

Position Statement #2 discusses the basic elements involved in the adhesion of overhead and vertical shotcrete on a waterproofing membrane and proper application techniques, emphasizing the use of mockups. This position paper also provides recommendations for contractors and owners, from ASA's perspective, on how to properly apply, specify, and inspect shotcrete applied against waterproofing membranes.

The ASA Underground Committee has three additional position statements in progress. The position statement "Innovation in Underground Shotcrete Materials" will cover new materials that do not fall into the formal definition of "concrete," but still use the shotcrete method for its application. The position statement "Mechanized Shotcrete in Underground Applications" will provide a general overview of equipment types and assemblies typically used in underground applications. It will discuss basic operational considerations for mechanized shotcreting and show some typical uses in tunneling and mining applications. The third position statement "Encapsulation of Reinforcement in Tunnel Shotcrete Final Linings" will provide guidance and recommendation for the proper encapsulation of reinforcement

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in tunnel shotcrete final linings. Most of the guidance provided in this statement will be based on referenced documents from ACI Committee 506, Shotcreting.

All position papers are developed by task groups that are led and assembled by ASA Underground Committee members. This work provides the industry with a valuable service and helps meet the ASA Underground Committee's mission to educate and promote the use and proper application of shotcrete in the underground construction and mining industries.

If you work with shotcrete in the tunneling and mining industry, consider becoming involved in ASA's Underground Committee. The committee welcomes feedback and requests. Contact info@shotcrete.org for more information.

The Road Ahead in 2020 and Beyond

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

As we wrap up 2019, we have come to a key turning point in the organization and management of our Association. In mid-December 2019, ASA's Board selected a new association management company to support our organization along with our existing full-time staff. Moving on from our current management company, where ASA has been hosted for nearly 20 years, will require a lot of time and effort. Overall, we expect the change, though perhaps a little painful through the transition, will provide us more flexibility and resources to grow our Association with an ability to cost-effectively use only those services that are needed to supplement our existing staff and volunteer resources.

Rest assured both Alice McComas, our Assistant Director, and I will be staying on board with ASA in this transition. We both are totally committed to ASA and continue to strive to make our Association of value to our members and to move shotcrete forward in the construction industry. Alice and I are fully responsible for the day-to-day operation of ASA. Though moving to a new association management company will need us to ramp up the new firm's knowledge of the way our Association works, we are confident our knowledge and experience about the core parts of our business will help smooth the transition. Our involvement is fully available and, in many ways, essential for continuity and efficiency of the move.

I apologize in advance for any bumps (hopefully not potholes) our members may experience in the transition to the new firm. The expectation is we will be fully live with the new firm by March 1, 2020. As you may expect, we have a lot of data, files, inventory, and equipment to move. Though our e-mail and website will stay the same, we will be getting new phone numbers and mailing addresses. Alice and I are staying in Michigan. The new firm has offices in Wakefield, MA, and Nashville, TN, that will service portions of our work. We will send out a notification e-mail with the new contact information to all members and subscribers with e-mail addresses in our database. We will also keep all informed with new contact information via our social media channels, eNewsletter "What's in the Mix," and our next issue of *Shotcrete* magazine.

There is no question that ASA has experienced substantial growth in outreach and recognition in the concrete construction industry over the past decade. Shotcrete placement is now acknowledged in globally recognized codes and standards, such as ACI 318, for its ability to create durable, high-strength structural concrete in a wide variety of applications. Nozzleman certifications are stronger than ever. We have new shotcrete inspector and contractor qualification programs. Our outreach efforts have introduced the state-of-the-art in shotcrete placement to over 1500 people in North America in 2019 alone. Alice and I are proud to have had the opportunity to be involved with ASA and contribute to that growth. We look forward to leveraging our new association management company's resources with our staff experience to advance ASA into 2020 and beyond.

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.

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Fiber-Reinforced Shotcrete—Applications and Testing Overview

By Antoine Gagnon and William "Bill" Geers

The addition of fibers to concrete and mortars as reinforcement is not a new concept. The ancient Egyptians used straw to reinforce mud bricks for use in structures like the core walls of the pyramids. During the first century AD, the Romans incorporated horsehair fibers in the construction of structures like the Coliseum to help prevent drying shrinkage cracking of the concrete.

In the modern era, the first scientific studies on the use of steel fibers to reinforce concrete date back to the 1960s and 1970s.[1,2] The use of steel fiber-reinforced shotcrete (FRS) was first introduced in the 1970s.[3] The first documented use of FRS was in 1973 by the U.S. Army Corps of Engineers in a tunnel adit project at the Ryrie Reservoir in Idaho. Soon thereafter it became well recognized that soil and rock excavations could effectively be stabilized with steel FRS and its use and acceptance increased globally. In the mid-1990s, the use of macrosynthetic fibers in shotcrete was developed and has increased with particular success in temporary support in underground mines where large deformation capacity is desired. Since the 1970s, thousands of projects have been successfully completed using fibers as reinforcement, including shotcrete, slabs-on-ground, composite steel decks, slabs-on-pile, and precast elements.

Ground support is the most widely used application of fibers in shotcrete today. However, there are other applications where the use of FRS is on the horizon. In 2018, the American Concrete Institute's (ACI) Committee 544, Fiber Reinforced Concrete, published a new guide titled "ACI 544.4R-18: Guide to Design with Fiber-Reinforced Concrete."[4] The document abstract states:

> "New developments in materials technology and the addition of field experience to the engineering knowledge base have expanded the applications of fiber-reinforced concrete (FRC). Fibers are made with different materials and can provide different levels of tensile/flexural capacity for a concrete section, depending on the type, dosage, and geometry. This guide provides practicing engineers with simple, yet appropriate, design guidelines for FRC in structural and nonstructural applications. Standard tests are used for characterizing the performance of FRC and the results are used for design purposes, including flexure, shear, and crack-width control. Specific applications of fiber reinforcement have been discussed in this document, including slabs-on-ground, composite slabs-on-metal decks, pile-supported ground slabs, precast units, **shotcrete**, and hybrid reinforcement (reinforcing bar plus fibers)."

In the section on FRS, the guide discusses other applications where the use of FRS would be a possible benefit: "Fiber-reinforced shotcrete is especially suitable for pools and skate parks with many curves, as it is shot against excavated soil, eliminating the cost of forms and steel installation." This guide also mentions that FRS is a good technique when repair and restoration are being contemplated, especially if there are access issues.

Challenges of Choosing the Right Fiber

Various fiber material types can be used in shotcrete such as steel, glass, synthetic, and natural fibers—each of which lend varying properties to the concrete (Fig. 1). In addition, it must be clear that the character or properties of the FRS changes with both the mixture design and the fiber's properties, geometries, distribution, orientation, and dosage. Fibers are further classified as either macro- or microfibers. Fibers with an equivalent diameter greater than 0.01 in. (0.3 mm) are macrofibers and equivalent diameter less than or equal to 0.01 in. are considered microfibers. Fibers can be used in both dry-mix and wet-mix shotcrete applications. The two most common fiber types used in FRS structural applications today are polypropylene macrofibers and steel fibers.

Fiber Performance in Concrete

The choice of the fiber most appropriate for use in a specific application can be confusing and not always well understood. There are no good or bad fibers—just the right fiber for the right application.

Reinforced concrete/shotcrete (fiber or conventionally reinforced) is a composite material where the concrete is strong in compression but weak in tension. Under loading conditions, hardened concrete can crack once its tensile strength is exceeded. Fibers used as structural

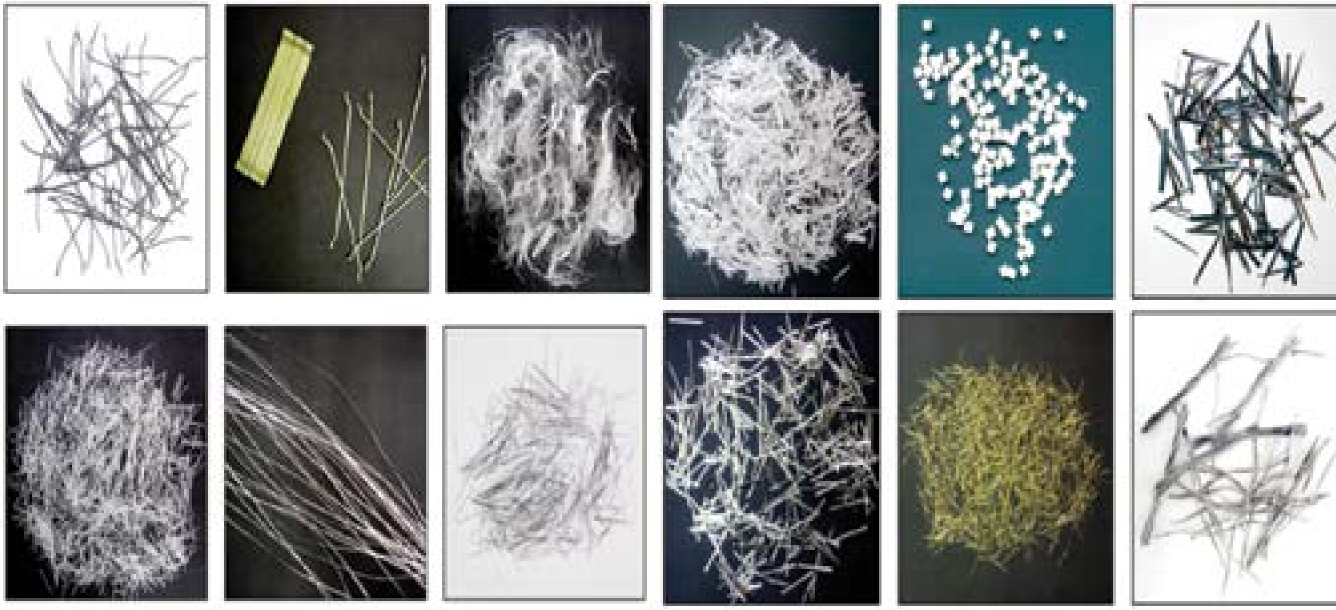

Fig. 1: Different types of fibers available

reinforcement are designed to provide tensile strength or energy absorption in the concrete matrix after the concrete cracks. As noted previously, the performance characteristics of the FRS is dependent on the mechanical properties of the fiber and the interaction between the materials within the concrete matrix. Understanding the fundamental differences in mechanical properties of a steel and a synthetic fiber, for example, may help in determining the right fiber to use in a specific application. Table 1 presents average Young's modulus and tensile strengths of hardened concrete and the two types of fibers, as well as the melting and creep temperatures of the fibers.

Understanding how the material properties impact the way that the fibers work within the concrete will help evaluate which fiber is best in a specific application. One of the key aspects to evaluate the performance of a FRS composite is the ratio between the Young's modulus of the fiber and the Young's modulus of the concrete. Note that the hardened concrete's Young's modulus is two to three times greater than the one of a synthetic fiber. What does this mean? While the FRS is in a plastic (fresh) state, synthetic fibers can provide better plastic shrinkage crack control. However, as the concrete hardens, and its Young's modulus exceeds the synthetic material's modulus—it takes more deformation for the synthetic fiber to provide its maximum tensile strength. This means that more deformation is usually necessary for synthetic fibers to provide an equivalent energy absorption. However, the anchor mechanism of any fiber and its ability to generate friction through deformation will affect the behavior of the composite.

On the other hand, a higher Young's modulus can create a different behavior in FRS. Steel fibers, for example, have a Young's modulus that is seven or more times greater than the concrete's. Steel fibers, unlike synthetics, are not used to provide plastic shrinkage crack control. However, as soon as the concrete hardens, and cracks begin to form in the matrix, the steel fibers more rapidly begin to absorb and then redistribute the tensile forces within the matrix. Steel fibers can hold cracks as they begin to form and keep them from opening further. This can also lead to multi-cracking and load redistribution in the structure. Controlling the width of cracks in a structural application is a fundamental difference between a steel and synthetic fiber. In a temporary ground support application where large deformations and crack widths can be required for a deformation driven system to work—in a mine, for example, synthetic fibers are very appropriate. However, in applications where crack width control is desired, steel fibers will be the preferred choice.

Another consideration when choosing the appropriate fiber, aside from crack widths or energy absorption, is the structure's exposure conditions. Essentially, in humid conditions with open cracks, synthetic fibers do not corrode

Table 1: Comparison of Material Properties: Concrete vs Steel Fibers vs Synthetic Fibers

Properties	Hardened concrete	Steel fibers	Synthetic fibers
Young's modulus (up to)	4350 ksi (30 GPa)	30,450 ksi (210 GPa)	1740 ksi (12 GPa)
Tensile strength (up to)	580 psi (4 MPa)	330 ksi (2.3 GPa)	95 ksi (0.65 GPa)
Material melting point	N/A	2732°F (1500°C)	329°F (165°C)
Material creep temperature	N/A	698°F (370°C)	>68°F (>20°C)

as carbon steel fibers can. When crack widths are small, however, corrosion usually doesn't affect long-term performance. On the other hand, because of the lower melting temperature and creep temperature of synthetic fibers, it may be less appropriate to use synthetic macrofibers as a structural reinforcement in a structure subject to elevated temperatures or fire. However, synthetic microfibers can help resist explosive spalling in high temperatures.

SPECIFICATION CHALLENGES

When it comes to specifying FRS, there are essential aspects to take into consideration. First, it is crucial for the engineer to define the intended purpose of the material in a structure, as it will influence the definition of its expected performance. It might appear trivial for some, but it is often overlooked or confused. For example, is it going to be used as initial lining for ground support or as final lining? Or is it going to be used as fire protection? FRS should be seen as a spectrum of mixture designs that can meet various needs. There is definitely no "one size fits all'' mixture in this spectrum.

In general, the design and specification of FRS is performance-based. This is usually more appropriate, as the interaction between the different ingredients and their synergetic effect can make a prescriptive specification ineffective and even unsafe. It is critical to understand the performance that is expected from FRS and, especially, how it will be assessed. This must align with the intended purpose of the material. Therefore, specifying the proper performance parameters and testing the right properties is of the utmost importance. For example, specifying the energy absorption (toughness) at 1.6 in. (40 mm) deflection in the ASTM C1550 test method on a round determinate panel (RDP) can be convenient for evaluating a mixture's performance at large deformation. However,

Fig. 2: Typical ASTM C1550 specimen (RDP) after testing

it should not be used as a specification parameter for a mixture to be used as final lining in a civil structure where only very thin cracks are to be tolerated. In this case, the performance parameter—energy absorption at large crack openings (Fig. 2)—is not consistent with the intended purpose of the material. Specifying flexural strength at smaller crack width would be more appropriate in this situation.

These ideas highlight the fact that different people involved in a project can have different perspectives on a mixture's performance and on its specifications. Because of their background and their approach to a project, some engineers will focus more on the peak strength of the material while some others may be more concerned about the post-cracking behavior of the material. In the end, there must be a connection drawn between the purpose of the material, the performance that is specified, and the test method used to assess it. Another essential aspect that is sometimes overlooked is the definition of failure, which is closely related to the purpose of FRS and its specified performance. Failure can have many definitions when it comes to FRS; it can be when the concrete first cracks, it can be when a maximum crack width is reached, it can be when the structure can no longer support a defined load, or it can be related to deformation or creep. This is an aspect that can cause misunderstandings in different phases of a project and must therefore be addressed as early as possible in a project.

Through the work of their technical committees, ASA and ACI have published numerous guides and reports that can help better understand the specificities of shotcrete, fiber-reinforced concrete, and FRS, thus clarifying how to specify FRS. ACI Committee 506, Shotcreting, offers guidance on the use and specification of shotcrete in 506R, "Guide to Shotcrete," and 506.2R, "Specifications for Shotcrete."[5,6] It also provides documents on the use of FRS and its use for underground applications.[3,7] Additionally, ACI Committee 544 is a good source of information through its multiple documents.[4,8-13] The ASA Underground Committee has also recently published position statements on Spraying Shotcrete Overhead in Underground Applications and Spraying Shotcrete on Synthetic Sheet Waterproofing Membranes.[14,15]

CHALLENGES IN THE LAB/FIELD

To get reliable information on the performance of FRS, one must understand the importance of sampling operations. The idea is to prepare a sample of the material that is as close to its real placement conditions as possible. This is true for concrete in general, but is particularly important for the unique material that is FRS. This applies to both laboratory conditions and field conditions. In the case of FRS, there are two main aspects that are of interest.

First, the changes in the mixture proportions of the concrete during the shotcrete placement process can affect the performance of a sample compared to the performance of the material in a real-size structure. Depending on the consistency of the mixture, the aggregate gradation, and other factors, the variance of rebound can change the aggregate/paste proportion and the fiber content.

Secondly, the orientation of fibers in the material is dependent on the spraying technique and specifically the size and geometry of the sampling mold. This is an important aspect, as fibers tend to orient in a plane that is perpendicular to the nozzle axis through the shotcrete placement process. Also, boundary effects with the limited panel size can affect the orientation of fibers in a sample compared to a larger structure. For that reason, larger sampling panels are usually preferred (Fig. 3).

Thus, it is essential to anticipate these behaviors by using adequate sampling panels, proper spraying technique, and by selecting the right parts of the sample to be used. The best example for this is the preparation of beam specimens for flexural testing. Even though it may be more convenient, a mold of the final size of the beam cannot be filled directly with FRS, as it would greatly affect its final composition and the orientation of fibers, thus changing its performance. ASTM C1140/C1140M, "Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels," is an essential reference for this.[16]

Because the need for larger samples leads to heavy specimens to carry, there has been growing interest to reduce the size of specimens without losing the quality of results. For that reason, researchers and users have been working on new standard test methods over the past few years. For example, smaller versions of the RDP and cylindrical core specimens have been developed and are currently evaluated.[17,18]

Fig. 3: Large molds to be sprayed with FRS for testing in a research project at Université Laval's Shotcrete Lab

There are still challenges in the interpretation of results from all the test methods available with regards to the actual real-life performances. There should be more attention paid to the behavior of a mixture rather than absolute numbers. Also, there should be more effort put into understanding how test methods provide information rather than trying to correlate between them. However, increasing the quality of the sampling operations and the preparation of specimens can definitely help increase the quality of the results and allow one to make an informed choice based on them.

Conclusions

In conclusion, the addition of fibers in shotcrete creates a unique concrete material and valuable tool for many different applications. The availability of FRS increases the potential solutions in various projects. This composite is particularly useful in underground environments where it performs well as ground support. To get the most out of FRS, there are a variety of fibers—mainly synthetic and steel—that can suit various needs. What is essential is to connect the purpose of using FRS, with its specified performance and the associated test method to verify results and its interpretation. There are still challenges to overcome in terms of specification and testing. This highlights the need for a common language between different owners, engineers, contractors, and testing labs in the industry. With the available technical documents provided by ASA and ACI, there should be more consensus on the benefits of using FRS.

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Antoine Gagnon *is a PhD Student in the Department of Civil and Water Engineering at Université Laval in Québec City, QC, Canada. The focus of his graduate research is in developing tools for the design and testing of fiber-reinforced shotcrete for ground support. In the last years, Gagnon has worked on shotcrete research projects with different companies in the industry. He is a member of the ASA Underground Committee and is involved in technical committees of the American Concrete Institute. He received his bachelor's degree and his master's degree in civil engineering from Université Laval.*

William "Bill" Geers *is Business Development and Technical Manager-USA/Canada for Bekaert Underground Solutions. He is a professional civil engineer with over 25 years of experience in the reinforced concrete industry. He is an active member and serves on the ASA Board of Directors. He is also an active member of the ACI Subcommittees 506 and 544, as well as ASTM Subcommittees C09.42, Fiber Reinforced Concrete, and C09.46, Shotcrete. In 2018, he was appointed to serve on the National Academies of Sciences, Engineering, and Medicine Transportation Research Board (TRB) AFF60 Standing Committee on Tunnels and Underground Structures and is a member of the Deep Foundation Institute (DFI).*


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Performance of Synthetic Sheet Waterproofing Membranes Sprayed with Steel Fiber-Reinforced Shotcrete

Testing for Waterproofing Membrane Integrity After Spraying

By Antoine Gagnon, Marc Jolin, and Jean-Daniel Lemay

The recent Position Statement #2, "Spraying Shotcrete on Synthetic Sheet Waterproofing Membranes," published by the ASA Underground Committee, pointed out many aspects critical to successful performance and raised some potential issues affecting the placement.[1] In the position statement, specific techniques are presented to prevent problems such as delamination, voids, or fallouts. In the discussion, the potential issue of steel fiber-reinforced shotcrete (FRS) causing damage and potentially puncturing the membrane was raised. From the experience of the committee and the available information, it was concluded that:

- The forces acting on the fiber are not strong enough to push the fiber into the membrane; and
- The fibers tend to orient parallel to the membrane on impact, thus reducing the risk of damage.

In parallel, a research project on this subject had been undertaken at Université Laval's Shotcrete Laboratory, with the results only recently available. This article presents the results of this investigation.[2] It is intended to support ideas presented in the ASA position paper and to help in the decision-making process when dealing with waterproofing membranes and FRS in underground projects.

RESEARCH PROJECT

The research project is aimed at evaluating the potential damage and performance reduction of synthetic sheet waterproofing membrane when using steel fiber-reinforced shotcrete. The main goal is to evaluate the watertightness of a waterproofing membrane when used with steel fiber-reinforced shotcrete placement. For this project, the conditions and materials used in an actual tunneling project in New York, NY, were reproduced as closely as possible in the laboratory.

The shotcreting operation and final composite included:

- A synthetic sheet waterproofing membrane applied on an FRS initial lining with two different surface finishes; and
- Subsequent FRS sprayed onto the membranes from each surface condition.

The integrity of the membrane in the final composite panel was then evaluated with two tests:

- An airtightness test; and
- A tensile strength test.

The airtightness test was used to evaluate the watertightness of the membrane. The test method and setup were adapted from previous research and implemented in Université Laval's Shotcrete Laboratory specifically for this project.[3] The tensile strength test was adapted from different membrane test standards. It was used to evaluate the behavior and maximum tensile strength of the membrane in its final state. Both tests are described with more details in the next sections.

METHODOLOGY AND MATERIALS

The shotcrete placement in this project follows the guidelines of ACI 506R-16, "Guide to Shotcrete."[4] The typical techniques and equipment used in similar research projects at Université Laval's Shotcrete Laboratory were used. Details on the methodology and materials are presented in the following sections.

Shotcreting Equipment

All the shotcreting operations in this project were conducted using the dry-mix process with an Aliva 246 gun, a 1.5 in. (38 mm) diameter hose, and a hydromix nozzle.

Shotcrete Mixture

To subject the membrane to real-life shotcreting conditions, a mixture similar to the one employed on the New York tunneling project was used in this project. The prebagged shotcrete mixture was manufactured by King Shotcrete Solutions. Table 1 presents an overall description of the mixture design. In this case, only the use of accelerator was omitted to facilitate overall finishing and cleaning operations. It is believed that the absence of accelerator would not significantly change the conclusions of this research. The steel fiber used was Dramix 3D provided by Bekaert Underground Solutions. The fibers were added to the shotcrete mixture during the mixing operation.

The synthetic sheet waterproofing membrane used in this project is the Mapeplan TU 20 provided by Mapei Underground Technology Team. It is a 0.08 in. (2 mm) thick polyvinyl chloride (PVC) membrane with a reported maximal tensile strength of 2175 psi (15 MPa) and maximum elongation of 250% at rupture. For this project, four sheets of membrane were used, each one measuring 20 x 20 in. (500 x 500 mm).

Production of Test Panels

The overall purpose of this project was to create a system that would closely represent the conditions of a membrane used underground with steel fiber-reinforced shotcrete.

The first step had two FRS substrate panels sprayed to replicate an initial lining. Both were sprayed at a dry consistency, with a relatively low water content in the dry-mix shotcrete. In the mining and tunneling industry, dry-mix shotcrete is usually sprayed with a dry consistency compared to typical mixtures in the repair industry. Both substrate panels were 24 x 24 in. (600 x 600 mm) wide and 4 in. (100 mm) thick.

Each panel received a different surface finish. For the first panel (Substrate 1), the surface was screeded. It was decided to screed the surface of one panel because screeding FRS tends to expose fibers on the surface (Fig. 1(a)). This was considered a harsh condition for the waterproofing membrane. The surface of the second panel (Substrate 2), was finished with a technique often referred to as a flash finish (Fig. 1(b)). In this operation, once the desired thickness is reached, the nozzleman moves the nozzle away from the surface to obtain a more uniform and smoother surface. Also, most fibers tend to be embedded within the shotcrete. Flash finishes are very common in the industry.

Figure 2 shows the shotcrete testing area after spraying of the panels. The panels were cured for 7 days in a fog room (73°F [23°C] and 100% RH) and then kept at room temperature and humidity (approximately 70°F [21°C] and 40% RH).

After producing the initial substrate panels, the next step was placing the synthetic sheet waterproofing membrane. The membrane was applied onto the substrate panels and fixed in place using a wooden frame. This frame served two purposes:

- It kept the membrane in place while the subsequent FRS layer was applied; and
- It acted as a bond breaker between the edges of the membrane and the fresh shotcrete.

In the setup used, a 2 in. (50 mm) strip around the edges of the membrane was covered with plywood, thus protecting the membrane from the impact of fresh FRS. The section of

Table 1: Mixture Design of Steel Fiber-Reinforced Shotcrete

Ingredients	Description
Binders	Portland cement and silica fume
Aggregates	Follow ACI 506 Gradation #2
Fibers	Bekaert Dramix 3D 93 lb/yd³ (55 kg/m³) (theoretical)
Admixtures	None

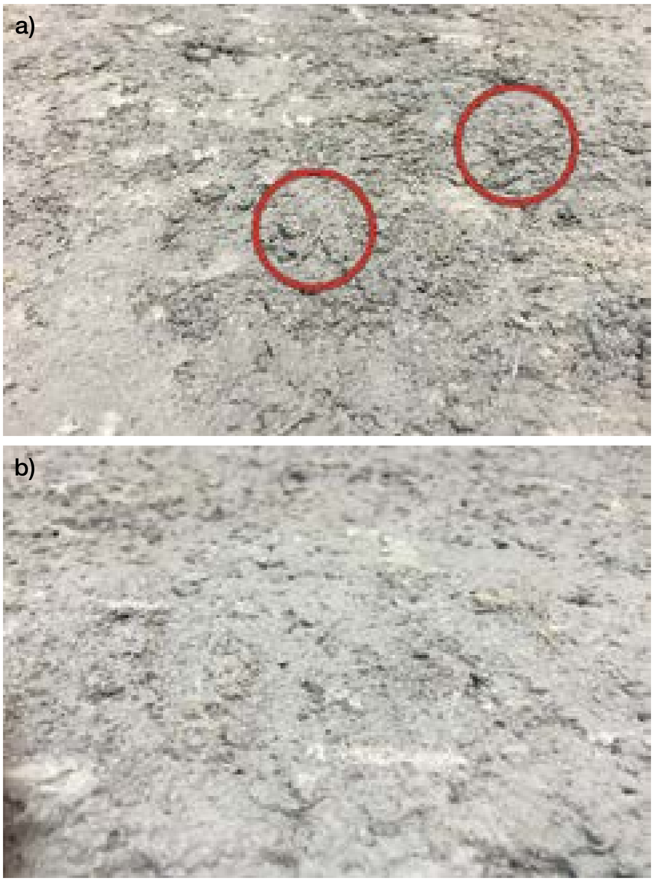

Fig. 1: (a) Close view of screeded finish with apparent fibers; and (b) flash finish with no apparent fiber

Fig. 2: Substrate panels after spraying

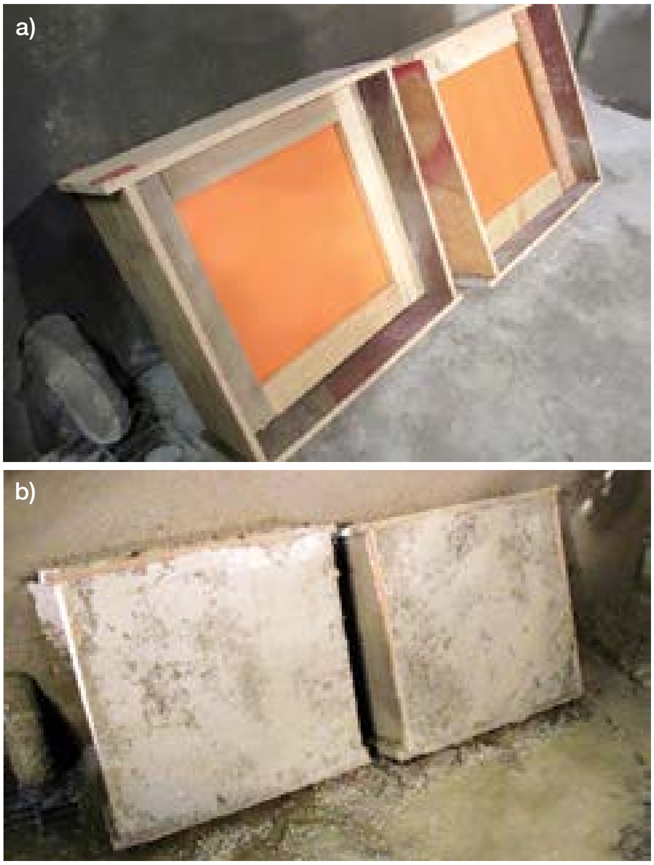

Fig. 3: (a) Substrate panels before; and (b) after second layer of FRS was applied

Fig. 4: Composite panels under loading frame

the membrane exposed to the spraying had dimensions of 16 x 16 in. (400 x 400 mm).

The final step in sample production was shotcreting the second layer. The second layer was shotcreted the same as the first layer. Figure 3 shows the setup before spraying and the composite panel after spraying. The composite panels were cured for another 7 days in the fog room (73°F and 100% RH) and then kept at room temperature and humidity (approximately 70°F and 40% RH).

After the second curing period, the two composite panels were placed in a hydraulic press to apply a pressure of 1.5 bar (22 psi). The pressure was maintained for 10 hours to simulate a pressure that would typically occur in underground applications. To ensure uniform contact between the panels, sand and plywood were placed between the panels to fill gaps. Figure 4 shows the composite panels under load in the loading frame (note that some of the panels in the picture could not be used).

Once removed from the hydraulic press, the composite panels were separated, and the waterproofing membranes carefully removed.

Airtightness Test

One of the goals of this project was to verify the synthetic sheet waterproofing membrane can retain its waterproofing ability after being applied onto FRS and subsequently sprayed with FRS. To evaluate this aspect, pressurized air was applied on the membrane specimens taken from the composite panels. The specimens were attached to a sealed steel frame connected to an air hose. Figure 5 shows the testing frame from the membrane side and from the air input side.

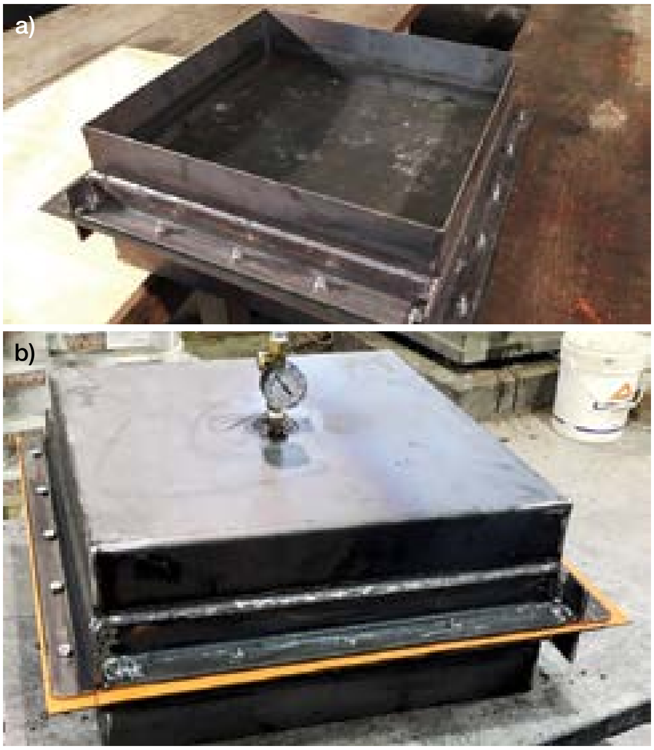

Fig. 5: (a) Testing frame from membrane side; and (b) from air input side

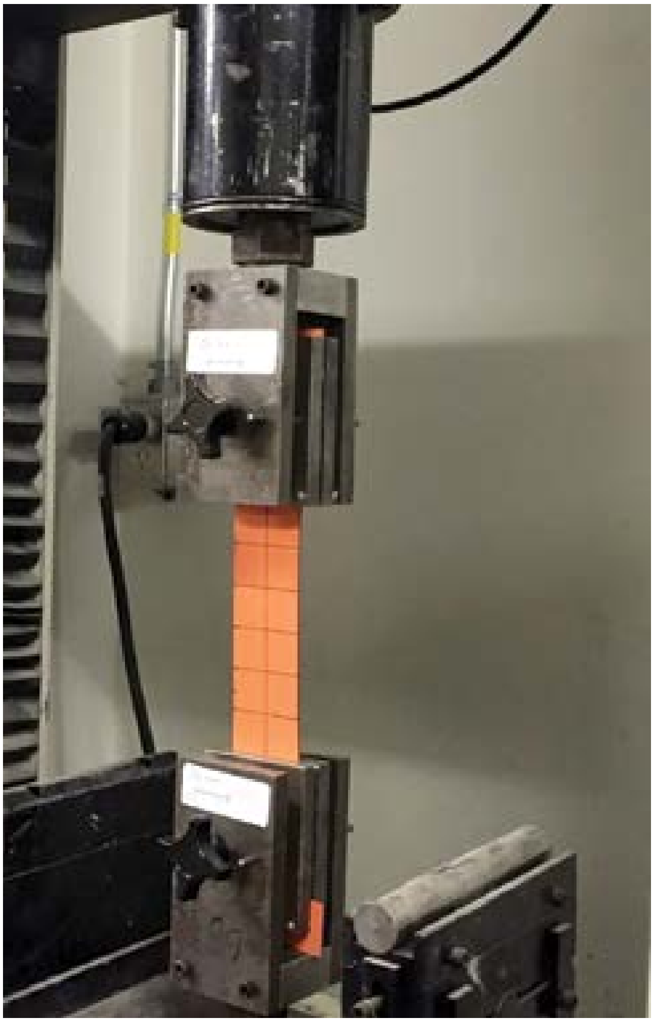

Fig. 6: Overall view of a membrane at the beginning of the test

Five holes on each side of the frame were drilled through the membrane to allow for bolts to go through and seal the frame. The contact surface on the outside edge of the frame was aligned with the protected section of the membrane (where the 2 in. wood strips were during the second shotcreting operation). The pressurized air was injected through a hose and a regulator. The pressure was maintained at approximately 50 psi (3.45 bar) for a few minutes to allow for observation.

Though a decrease of pressure could have been measured, the reported results from this test are completely qualitative. The membrane was thoroughly inspected for perforations or any unusual deformations (for example, bubbles, localized deformations, and tears) that may have appeared while the membrane was pressurized.

Fig. 7: Waterproofing membrane in strips before testing

Tensile Strength Test

The second test evaluated the impact of steel FRS on the physical properties of the waterproofing membrane. In this test, strips of the membranes were cut and loaded in tension until they either broke or the maximum displacement of the testing frame was reached. Figure 6 presents the test setup.

The tensile specimens were cut in strips of 2 in. wide by 11 in. (280 mm) long (Fig. 7). Each end of the specimen had 2.5 in. (64 mm) inside the grip, leaving 6 in. (150 mm) in the middle section. In preparation for testing, six specimens (control) were used to validate the setup, the specimen dimensions, and the general behavior of the membrane during the test. Table 2 presents the testing conditions for each specimen.

Because none of the waterproofing membranes were punctured by FRS during the creation and dismantling of the panels, it was decided to evaluate the potential reduction in strength if a hypothetical fiber was to puncture a membrane. To simulate a fiber puncturing the membrane and the effect on the membrane's properties, unsprayed specimens D-1 and D-2 had defects deliberately created using a 1/16 in. (1.6 mm) diameter drill bit. A single hole was made and placed in the middle of the membrane.

RESULTS

The following sections present a combination of qualitative observations and quantitative measures obtained through the shotcreting operation and testing process.

Table 2: Testing Conditions for Membrane Specimens for Tensile Strength Test

Identification	Membrane condition	Defects
U-1 and U-2	Unsprayed membrane	—
S1-1 and S1-2	Sprayed on substrate I	None*
S2-1 and S2-2	Sprayed on substrate II	None*
D-1 and D-2	Unsprayed membrane	Artificial defect

*Based on observations during airtightness test (results presented in this article)

Visual Inspection

After taking apart the composite specimens, the shotcrete surfaces of the second layer—the one that was sprayed onto the membrane—all presented similar aspects:

- A smooth surface;
- No visible fibers or aggregate; and
- A "purplish" color (probably a discoloration from the membrane).

This agrees with general shotcreting experience and observations. As the shotcrete hits a hard substrate, it must first create a paste bed before aggregates and fibers can stick to the surface and start embedding in the shotcrete. This is substantiated by the fact that rebound is always higher in the first few millimeters of shotcrete placement on a hard substrate. Also, fibers in FRS tend to orient in a plane parallel to the receiving surface upon impact. Finally, the kinetic energy of a fiber and its surrounding shotcrete material does not appear to be high enough to push the fiber into the membrane. These observations suggest that none of the fibers from the second layer were in contact with the membrane. Figure 8 presents a close view of the smooth shotcrete surface.

There was no visible damage on the membrane from either of the finishes of Substrate 1 or 2. There was no visible dust or wear on the surface exposed to the second layer shotcrete placement. On the side of the membrane in contact with the first layer, dust and small indentations of aggregate were visible. Most of the dust could easily be swept away by simply wiping a glove on the surface. The difference in the finish between Substrate 1 and 2 (screeded and flash finish) did not influence the integrity of the membrane.

Fig. 8: Closeup view of shotcrete layer sprayed onto waterproofing membrane

Fig. 9: Inflated membrane at 50 psi of air pressure

Airtightness Test

None of the waterproofing membranes from either Substrate 1 or 2 showed any sign of air leakage during the airtightness test. Specimens from both substrates seemed to have similar deformation at the maximum test air pressure. For all specimens, the membrane first started inflating as the air started entering the chamber (refer to Fig. 9). Once the membrane's maximum deformation was reached, the pressure started rising and was maintained at 50 psi.

Tensile Strength Test

The tensile strength test was conducted on an electromechanical testing system that allows for large displacements. Despite the large displacement capacity, the limit of the frame was reached with some specimens and the test had to be stopped. This displacement was equivalent to a deformation of approximately 370% for a 6 in. long specimen. Therefore, specimens could either rupture or reach the testing frame displacement limit in this test.

Table 3 presents the maximum load, the maximum deformation, and the criterion reached to stop the test for all specimens. The deformation was calculated using the crosshead displacement and the specimen length between the clamping jaws (6 in.).

Note that the deformation presented in Table 3 is for comparative purposes only. Unfortunately, the clamping jaws used in this test could not hold the membrane specimen completely, thus it partially slipped at large deformations. In Fig. 10, the circled line was initially aligned with the upper edge of the clamping jaw. This shows that part of the specimen initially inside the clamping jaw was stretched and pulled out from the jaw. This explains why the deformations presented in Table 3 are much larger than the maximum deformation specification in the synthetic sheet waterproofing membrane technical datasheet (250%).

Though the maximum deformation presented cannot be directly used to determine the true ultimate deformation at rupture, the test results still allow for a comparison between the different membrane conditions.

A specimen from the sprayed membranes group (S2-1) ruptured before reaching the maximum displacement, seemingly presenting a different behavior from the other samples from the shotcreted panels. However, it should be noted that the failure occurred in the portion of the specimen between the clamping jaws. Thus, it is most likely caused by a strain concentration from uneven pressure inside the clamping jaws. The behavior of Specimen S2-1 is more similar to the behavior of the sprayed and unsprayed membranes than it is to the behavior of unsprayed membranes with artificial defects.

Table 3: Results from Tensile Strength Test

Identification	Membrane condition	Maximum load, N	Maximum deformation, %	Stopping criterion
U-1	Unsprayed	(>) 1350	376	Frame limit
U-2	Unsprayed	(>) 1241	378	Frame limit
S1-1	Sprayed on Substrate 1	(>) 1456	372	Frame limit
S1-2	Sprayed on Substrate 1	(>) 1405	376	Frame limit
S2-1	Sprayed on Substrate 2	1213	369	Membrane rupture
S2-2	Sprayed on Substrate 2	(>) 1225	376	Frame limit
D-1	Unsprayed with artificial defect	1062	273	Membrane rupture
D-2	Unsprayed with artificial defect	1070	268	Membrane rupture

The tensile results show that the presence of a defect significantly reduces the maximum deformation at the end of the test (refer to D-1 and D-2). Figure 11 shows that even a small defect in the membrane ultimately leads to the premature rupture of the membrane.

Fig. 10: Membrane slipping outside the clamping jaw for crosshead displacement of 14 in. (350 mm)

Conclusions

The objective of this research project was to evaluate the effect of steel FRS with an embedded synthetic sheet waterproofing membrane on the watertightness of the membrane and its performance. The results show that neither the surface condition of the initial lining of FRS under the membrane nor a final lining sprayed onto the membrane affected its integrity or performance. In the air tightness test, the air pressure was maintained by the membrane after installation within the composite panel, suggesting it would remain watertight in service. Also, the specimens in the tensile strength test maintained their physical properties except when a hypothetical puncture was simulated.

The manipulation and installation of the membrane is, in the authors' opinion, much more critical than the effect of an initial or final FRS lining in contact with the membrane. For example, anchors are likely more of an issue in terms of watertightness and membrane integrity than FRS. Because of the accumulation of paste due to initial increased rebound before fiber retention, the orientation of fibers and their inability to penetrate the membrane upon impact, fibers are typically not in direct contact with the membrane when a second layer of FRS is sprayed onto the membrane. Finally, the surface finish of an initial FRS layer that subsequently has a waterproofing membrane applied onto it does not appear to influence the integrity of the membrane. In the authors' opinion, neither aggregates nor fibers in FRS seem to be an issue when in contact with such waterproofing membrane.

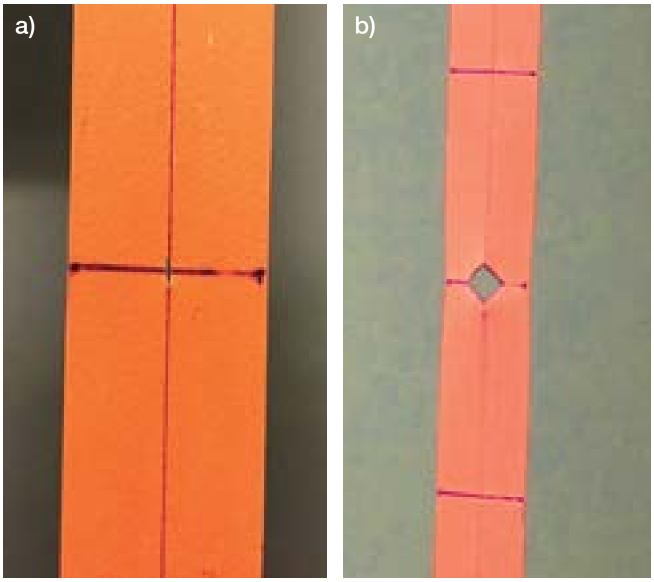

Fig. 11: (a) Specimen D-1 (artificial defect) with crosshead displacement of 9.6 in. (244 mm); and (b) displacement of 16.1 in. (410 mm). The original dimension of the hole was 1/16 in.

Acknowledgments

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Antoine Gagnon *is a PhD Student in the Department of Civil and Water Engineering at Université Laval, Québec City, QC, Canada. The focus of his graduate research is in developing tools for the design and testing of fiber-reinforced shotcrete for ground support. In the last years, Gagnon has worked on shotcrete research projects with different companies in the industry. He is a member of the ASA Underground Committee and is involved in technical committees of the American Concrete Institute. He received his bachelor's degree and his master's degree in civil engineering from Université Laval.*

Marc Jolin*, FACI, is a Full Professor in the Department of Civil and Water Engineering at Laval University, Quebec, QC, Canada. He received his PhD from the University of British Columbia, Vancouver, BC, Canada, in 1999. An active member of Centre de Recherche sur les Infrastructures en Béton (CRIB), he is currently involved in projects on automated placement of shotcrete, modeling of rebound, equipment optimization, and shotcrete rheology. Jolin is an ASA member; an ACI Examiner for Shotcrete Nozzleman Certification (wet- and dry-mix processes); Chair of ACI Committee 506, Shotcreting; Secretary of C601-I, Shotcrete Inspector Certification; and a member of ACI Committee C660, Shotcrete Nozzleman Certification.*

Jean-Daniel Lemay *is a former Research Engineer at the Shotcrete Laboratory at Université Laval. He received his bachelor's degree in civil engineering in 2011 and his MSc in civil engineering on shotcrete technology in 2013 from Université Laval. He has been involved with every aspect of shotcrete, from nozzling to mixture design and equipment repairs. He currently works as a forensic engineer for CEP Forensic in Québec City. He is a member of the American Concrete Institute (ACI) and International Concrete Repair Institute (ICRI), an ACI supplemental examiner for the Concrete Field Testing Technician Grade 1 certification, and an ACI examiner for Shotcrete Nozzleman certification (dry-mix and wet-mix) and Adhesive Anchor Installer certification.*

The Newly Launched ACI Shotcrete Inspector Certification Program

By Randle Emmrich, Charles Hanskat, and Marc Jolin

The Shotcrete Inspector Certification program began out of the need in the industry to have knowledgeable individuals inspecting shotcrete projects. Shotcrete contractors often find themselves having to educate project inspectors on the details needed for quality shotcrete placement. Shotcrete is a superior placement option in many cases, yet unfortunately, the expertise in evaluating the work is often non-existent. Many contractors and specifiers are faced with situations on jobsites where the lack of shotcrete-specific knowledge from the inspector has either limited the use of shotcrete or created potential litigious situations. The industry needs a knowledgeable on-site inspector, not necessarily an expert in contract documents or even a laboratory tester. As is the case with form-and-pour concrete, an inspector who has demonstrated basic shotcrete knowledge will be in a much better position to promote high-quality work.

Background

ACI Committee C660, Shotcrete Nozzleman Certification, identified the need for Shotcrete Inspectors and presented this to the ACI Certification Programs Committee. A focus study was conducted, and the results confirmed the industry need to proceed with the development of an Inspector Certification program. The objective of the Shotcrete Inspector Certification program is to verify a Shotcrete Inspector possesses the basic knowledge in both dry-mix and wet-mix shotcrete to:

- Recognize key details essential for quality shotcrete placement (surface preparation, placement, reinforcement encapsulation, rebound and overspray control, curing, finishing, and protection);
- Knowledgably observe preconstruction and material panel preparation and handling (panel size, curing, protection, transportation, coring, and sawing); and
- Judiciously sign off on the acceptance of the final shotcrete work.

Requirements

Because certification as a Shotcrete Inspector requires more than simply being knowledgeable about shotcrete, general concrete knowledge is also stipulated. Prerequisites for becoming a Shotcrete Inspector includes:

- The successful completion of a written examination (an open book exam pulling from the complete ACI 506 library, ASTM Standards, CCS-4, ASA's Safety Guidelines, and ACI hot- and cold-weather concreting documents);
- Certification as an ACI Concrete Field Testing Technician – Grade I (currently or previously with a successful completion within 1 year of the Shotcrete Inspector exam); and
- Demonstrated satisfactory education and work experience.

The education and work experience required for Shotcrete Inspector certification is 3 years of satisfactory work experience in at least one of the following areas:

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

The scope of the Shotcrete Inspector Certification is broad and encompasses a vast amount of information. For more information, visit **www.concrete.org/certification**. An understanding of the following are some examples of the types of knowledge required to achieve certification:

- What is structural shotcrete placement;
- The characteristics of the wet- and dry-processes;
- The purpose of preconstruction testing;
- The QA and QC requirements as required by the contract documents;
- The different types of shotcrete panels and their purposes;
- The objectives of a specific test program for a particular project;
- The differences in testing shotcrete versus form-and-pour concrete;
- The different tests for fresh properties of dry- versus wet-mix shotcrete;
- The relationship between equipment, material, nozzleman skills, and shotcrete quality;
- How shotcrete test specimens are obtained; and
- How environmental conditions affect shotcrete placement.

SUCCESSFUL PILOT SESSION

A pilot session was conducted this fall where both the full-day ASA Shotcrete Inspector Education seminar and the ACI Shotcrete Inspector Certification exam were offered, along with the newly compiled CP-61Pack – Shotcrete Inspector Reference Package (now available for the open book exam). Valuable feedback was garnered from the pilot attendees, and with that feedback, the final product was ready for launch at The ACI Concrete Convention and Exposition – Fall 2019 in Cincinnati, OH.

ASA SHOTCRETE INSPECTOR EDUCATION

Though the ASA Shotcrete Inspector Education is not a required component of the ACI Shotcrete Inspector Certification program, it is a recognized educational alternative, fulfilling 1 year of the 3-year required work experience identified in the program. This is a great learning opportunity for both seasoned and novices in the field, providing substantive content to reinforce the material covered in the written ACI Shotcrete Inspector Certification exam. The Education seminar is also beneficial to engineers, specifiers, building officials, general contractors, supervisors, project managers, and others who would benefit from a better understanding of how to recognize quality shotcrete application. If you are interested in the education or certification, more information and scheduled events can be found at **www.shotcrete.org/pages/education-certification/shotcrete-inspector-program.htm**. If you are interested in hosting or coordinating an event near you, please contact ASA (info@shotcrete.org).

SUMMARY

ASA acknowledges the hard work of ACI Subcommittee C660-I and ACI Certification staff who put this comprehensive program together. Though there are many inspectors with a thorough knowledge of concrete construction, few know the details required for quality structural shotcrete placement. This program is a valuable addition to extend the knowledge of existing concrete inspectors. Better knowledge of shotcrete on our concrete construction projects will let us further promote the safe and beneficial use of shotcrete and increase its recognition as an equal or superior to the more conventional form-and-pour placement method in more diverse applications.

***Randle Emmrich** is Vice President for Coastal Gunite Construction Company, Bradenton, FL. She received her BS in civil engineering from Bucknell University, Lewisburg, PA. In her 20 years in the shotcrete business, she has overseen many projects, including the rehabilitation of bridges, piers, manholes, aqueducts, and sewers. Her projects have served various clients, such as the U.S. Army Corps of Engineers, ESSO Inter-America, the Maryland Transportation Authority, the Virginia Department of Transportation, the City of Atlanta, and the City of Indianapolis. Emmrich serves as Secretary of the ASA Membership Committee. She is also a member of ASCE; Chair of ACI Committee C660, Shotcrete Nozzleman Certification; and ACI Subcommittee C601-I, Shotcrete Inspector Certification; and a member of ACI Committee 506, Shotcreting.*

***Charles Hanskat** is the current ASA Executive Director. He received his BS and MS in civil engineering from the University of Florida, Gainesville, FL. Hanskat is a licensed professional engineer in several states. He has been involved in the design, construction, and evaluation of environmental concrete and shotcrete structures for over 35 years. Hanskat is also a member of ACI Committees 301, Specifications for Structural Concrete; 350, Environmental Engineering Concrete Structures; 371, Elevated Tanks with Concrete Pedestals; 372, Tanks Wrapped with Wire or Strand; 376, Concrete Structures for Refrigerated Liquefied Gas Containment; 506, Shotcreting; and Joint ACI-ASCE Committee 334, Concrete Shell Design and Construction. Hanskat's service to the American Society of Civil Engineers (ASCE), the National Society of Professional Engineers (NSPE), and the Florida Engineering Society (FES) in over 50 committee and officer positions at the national, state, and local levels was highlighted when he served as State President of FES and then as National Director of NSPE. He served as a District Director of Tau Beta Pi from 1977 to 2002. He is a Fellow of ACI, ASCE, and FES and a member of ACI, NSPE, ASTM International, AREMA, ICRI, and ASCC.*

***Marc Jolin**, FACI, is a Full Professor in the Department of Civil and Water Engineering at Laval University, Quebec, QC, Canada. He received his PhD from the University of British Columbia, Vancouver, BC, Canada, in 1999. An active member of Centre de Recherche sur les Infrastructures en Béton (CRIB), he is currently involved in projects on automated placement of shotcrete, modeling of rebound, equipment optimization, and shotcrete rheology. Jolin is an ASA member; an ACI Examiner for Shotcrete Nozzleman Certification (wet- and dry-mix processes); Chair of ACI Committee 506, Shotcreting; Secretary of C601-I, Shotcrete Inspector Certification; and a member of ACI Committee C660, Shotcrete Nozzleman Certification.*

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Shotcrete Incorporated into ACI 318-19 Building Code

A supplement to the commentary to ACI 318-19

By Charles Hanskat, Terence C. Holland, and Bruce A. Suprenant

Since the shotcrete process originated well over 100 years ago, improvements in materials, equipment, and placement techniques have enabled it to become a well-proven method for structural concrete placement. The efficiency and flexibility of shotcrete have been used to great advantage in sizable structural projects, as the high-velocity impact inherent in the process provides the compaction needed to turn low-slump concrete into freestanding vertical and overhead placements with minimal formwork.

Table 1: Provisions in 2015 IBC Section 1908 Shotcrete[2]

Provision	Title
1908.1	General
1908.2	Proportions and materials
1908.3	Aggregate
1908.4	Reinforcement
1908.4.1	Size
1908.4.2	Clearance
1908.4.3	Splices
1908.4.4	Spirally tied columns
1908.5	Preconstruction tests
1908.6	Rebound
1908.7	Joints
1908.8	Damage
1908.9	Curing
1908.9.1	Initial curing
1908.9.2	Final curing
1908.9.3	Natural curing
1908.10	Strength tests
1908.10.1	Sampling
1908.10.2	Panel criteria
1908.10.3	Acceptance criteria

Shotcrete has been incorporated into the International Building Code (IBC) for many years, but there was no assigned responsibility for reviewing and updating the provisions. Further, shotcrete was not expressly covered in the ACI 318 Code. To address these shortcomings, during the 2019 code cycle, Jack Moehle, Chair of ACI Committee 318, Structural Concrete Building Code, requested that ACI 318 subcommittees work to incorporate shotcrete provisions into the ACI 318 Code. Thus, ACI Subcommittees 318-A, General, Concrete, and Construction, and 318-B, Anchorage and Reinforcement, started a 5-year journey, ending in the successful inclusion of shotcrete into ACI 318-19.[1] Here is that story.

IBC SHOTCRETE PROVISIONS

Conversations between ACI and International Code Council (ICC) staff indicated that it would be possible to delete the shotcrete provisions from the IBC upon satisfactory incorporation of shotcrete into the ACI 318 Code. Thus, the first task for the subcommittee members was to study the shotcrete provisions in the IBC. The topics covered in 2015 IBC Section 1908 Shotcrete are shown in Table 1.[2] A table prepared for the subcommittees to summarize the shotcrete provisions in the 2000, 2003, 2006, 2009, 2012, and 2015 editions of the IBC showed that very little change had occurred since 2000. Further, it was evident that the 2000 IBC provisions[3] were primarily based on an extremely dated document, "Guide to Shotcrete (ACI 506R-90)."[4]

ACI SHOTCRETE INFORMATION

The next task for subcommittee members was to review relevant, current information in the following ACI documents:

- "Guide to Shotcrete (ACI 506R-16)"[5];
- "Guide to Fiber-Reinforced Shotcrete (ACI 506.1R-08)"[6];
- "Specifications for Shotcrete (ACI 506.2-13 (Reapproved 2018))"[7];
- "Guide for the Evaluation of Shotcrete (ACI 506.4R-94 (Reapproved 2004))"[8];

- "Guide for Specifying Underground Shotcrete (ACI 506.5R-09 (Reapproved 2016))"[9]; and
- "Visual Shotcrete Core Quality Evaluation TechNote (ACI 506.6T-17)."[10]

It should be noted that the latest edition of "Guide for the Evaluation of Shotcrete (ACI 506.4R-19)"[11] was approved too late to be considered in developing the shotcrete provisions for ACI 318-19.

IBC VERSUS ACI CODE—APPLYING ASTM STANDARDS

The 2015 IBC provisions in Section 1908 Shotcrete were created well before ASTM developed testing standards for shotcrete, so no ASTM standards on shotcrete were referenced. Therefore, the IBC provisions considered for inclusion in ACI 318 had to be modified to reflect ACI Code usage of ASTM standards. The following ASTM standards for shotcrete were used and cited in ACI 318-19:

- C1385/C1385M-10(2017), "Standard Practice for Sampling Materials for Shotcrete";
- C1140/C1140M-11, "Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels";
- C1141/C1141M-15, "Standard Specification for Admixtures for Shotcrete";
- C1436-13, "Standard Specification for Materials for Shotcrete";
- C1480/C1480M-07(2012), "Standard Specification for Packaged, Pre-Blended, Dry, Combined Materials for Use in Wet or Dry Shotcrete Application"; and
- C1604/C1604M-05(2012), "Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete."

INCORPORATING SHOTCRETE IN ACI 318-19

ACI 318-14[12] did not include the word "shotcrete," and it was silent as to whether the provisions applied to shotcrete. If shotcrete had been incorporated into the ACI Code prior to the 2014 edition, it would have been appropriate to develop a new chapter on shotcrete that included all relevant provisions on materials, placement, and acceptance. However, that was not a feasible option within the member-based code organization implemented in the 2014 edition of the Code.

Thus, the incorporation of shotcrete into the Code required the application of two principles in the context of the complete 318 Code:

- Shotcrete is cast-in-place concrete; and
- Shotcrete is a construction placement method.

In effect, the subcommittees' primary objective was to implement shotcrete as a cast-in-place method, and this required them to consider and implement the following rules:

- Respect the intent of the IBC shotcrete provisions;
- Update the IBC shotcrete provisions to reflect current ACI information;
- Use ASTM standards in the development of the Code language; and

a)

b)

Shotcrete has been widely used for over a century: (a) a crew poses with their equipment in the 1920s; and (b) a crew places a foundation wall in the 1940s

- Integrate shotcrete provisions to be compatible with existing Code language.

This required shotcrete provisions to be incorporated into ACI 318 where it was appropriate to modify the provisions in the 2014 edition. Thus, shotcrete provisions are distributed throughout the relevant sections of the ACI Code. As a result, ACI 318-19 contains 135 instances of the word "shotcrete."

ACI 318-19: THE RESULT

Drafts of the shotcrete provisions were vetted by Marc Jolin, Chair of ACI Committee 506, Shotcrete, and Charles Hanskat, Executive Director of the American Shotcrete Association (ASA), along with members of

Shotcrete is ideal for placing complex structures: (a) the curved enclosure wall of Stanford University's Bing Concert Hall comprises shotcrete with a sand float finish; (b) a certified nozzle operator and a blowpipe operator construct mockup panels for the enclosure wall; and (c) crews placed the 12 in. (300 mm) thick enclosure wall in multiple lifts, using a removable screed rail to control the thickness

Photos courtesy of Joseph J. Albanese, Inc.

ACI Subcommittee 318-A. After numerous 318 subcommittee and 318 main committee ballots, and review by the ACI Technical Activities Committee (TAC) and the public, the shotcrete provisions were incorporated into ACI 318-19. Table 2 shows the covered shotcrete topics and their locations within ACI 318-19.

Table 2: Shotcrete provisions and relevant ACI 318-19 sections[1]

Topic covered	Section
Terminology	2.3*
Freezing and thawing	19.3.3.3 through 19.3.3.6
Reinforcement	25.2.7 through 25.2.10, 25.5.1.6, and 25.5.1.7
When shotcrete is required or permitted	26.3.1, 26.3.2
Materials	26.4.1.2, 26.4.1.4, and 26.4.1.6
Proportioning mixtures	26.4.3
Documentation of mixtures	26.4.4.1
Placement and consolidation	26.5.2.1
Curing	26.5.3
Joints	26.5.6
Evaluation and acceptance	26.12

*The terms shotcrete mockup panel, shotcrete test panel, shotcrete, and wet- and dry-mix shotcrete were added to Section 2.3—Terminology

Table 3: Total air content for shotcrete (based on Table 19.3.3 in ACI 318-19[1])

Mixture type	Sampling location	Target air content, %		
		F1	F2	F3
Wet-mix shotcrete	Before placement	5.0	6.0	6.0
Dry-mix shotcrete	In-place	N/A*	N/A*	4.5

*Entrained air is not required in dry-mix shotcrete for these exposures

EXTENDED COMMENTARY

The following sections provide extended commentary on ACI 318-19 provisions addressing air content in shotcrete and certification requirements for nozzle operators. In addition, an erratum on acceptance testing requirements for shotcrete is discussed.

Air Content of Shotcrete

Both wet-mix and dry-mix shotcrete can be air entrained for enhanced resistance to cyclic freezing and thawing. Provisions for air entrainment are provided in Table 3 for shotcrete exposed to cycles of freezing and thawing. The higher air content of wet-mix shotcrete sampled at the point of delivery accounts for expected air losses during shooting.

Dry-mix shotcrete without air entrainment has performed well in freezing-and-thawing environments with no exposure to saltwater or deicing salts.[5,13] For exposure to saltwater or deicing salts, air-entraining admixtures, in either a wet or dry form, can be added to dry-mix shotcrete to provide the required air content for durability in these exposures.[14]

ACI SUBCOMMITTEE 318-B UPDATES REINFORCEMENT FOR SHOTCRETE

ACI Subcommittee 318-B members David Darwin, the University of Kansas, and Neal Anderson, Simpson Gumpertz and Heger, were responsible for getting the shotcrete reinforcement details into ACI 318-19. The minimum spacing for reinforcement for shotcrete is provided in Provisions 25.2.7 through 25.2.10. Noncontact lap splices for shotcrete are covered in Provision 25.5.1.6 and contact lap splices for shotcrete are covered in Provision 25.5.1.7. These reinforcement provisions provide for the use of shotcrete mockup panels to demonstrate clear spacing and lap splices other than those permitted by the Code.

In wet-mix shotcrete, air entraining is introduced into the concrete mixture before pumping and placing the concrete. The air content can be tested at the point of delivery using normal ASTM testing standards. In dry-mix shotcrete, the dry concrete materials are wetted at the nozzle so there is no opportunity to test for air content until the mixture is placed. Thus, ACI 318 does not include a specific testing method for evaluating the air content of dry-mix shotcrete and requires the licensed design professional to specify a method to be used.

Field measurements of air content of dry-mix shotcrete have been obtained by shooting the material directly into a bowl of an air meter.[14] Samples for air content testing can also be taken from material shot into test panels, into a wheelbarrow, or onto the ground. These samples can then be used for testing in accordance with ASTM C231/C231M, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method."[15]

Certification

ACI 318-14 incorporated certification requirements for concrete field and strength testing technicians and adhesive anchor installers. Similarly, certification requirements are included in ACI 318-19 for shotcrete nozzle operators: "A certified shotcrete nozzle operator shall place all shotcrete" (Provision 26.5.2.1(o)). The Commentary Provision R26.5.2.1(o) provides the following information: "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)."

An Erratum on Strength Acceptance

After publication of ACI 318-19, Jim Klinger, Conco Companies, an incoming member of ACI Subcommittee 318-A, spotted an inconsistency in Section 26—Evaluation and acceptance of hardened concrete. In their attempt to match the acceptance criteria for standard-cured specimens, the subcommittee members provided two criteria for shotcrete. Klinger observed that these two criteria were not consistent. The error was discussed during the ACI Subcommittee 318-A meeting in Cincinnati, OH, and it was agreed to modify the wording as shown below. Strikethrough font indicates text deleted from the Code;

underlined text has been added. An erratum to ACI 318-19 Provision 26.12.4.1 will be issued to make this change:

26.12.4.1 Compliance requirements:

(a) Specimens for acceptance tests shall be in accordance with (1) and (2):
   (1) Test panels shall be prepared in the same orientation and by the same nozzle operator placing shotcrete.
   (2) Cores shall be obtained, conditioned, and tested in accordance with ASTM C1604.

(b) Strength of a shotcrete mixture shall be acceptable if ~~(1) and (2) are satisfied:~~
   ~~(1) Every arithmetic average of the strengths from three consecutive test panels equals or exceeds f_c'.~~
   ~~(2) The~~ average compressive strength of three cores from a single test panel is not less than **0.85** f_c', with no core having a strength less than **0.75** f_c'.

(c) If ~~either of~~ the requirement~~s~~ of 26.12.4.1(b) ~~are~~ is not satisfied, steps shall be taken to increase the average of subsequent strength results.

(d) Requirements for investigating low strength-test results shall apply if the requirement~~s~~ of ~~26.12.6.1(b)(2)~~ 26.12.4.1(b)~~(2) are~~ is not met.

LOOKING TO THE FUTURE

Shotcrete placement has been successfully used in structural concrete work for decades. Up-to-date requirements reflecting current shotcrete technology have been incorporated into ACI 318-19. It is the expectation of the committee that these requirements, like all other requirements in the Code, will be reviewed and updated on a continuing basis as the industry advances. The committee looks forward to receiving feedback from the shotcrete community as the provisions are implemented in practice.

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4. ACI Committee 506, "Guide to Shotcrete (ACI 506R-90)," American Concrete Institute, Farmington Hills, MI, 1990, 81 pp.

5. ACI Committee 506, "Guide to Shotcrete (ACI 506R-16)," American Concrete Institute, Farmington Hills, MI, 2016, 52 pp.

6. ACI Committee 506, "Guide to Fiber-Reinforced Shotcrete (ACI 506.1R-08)," American Concrete Institute, Farmington Hills, MI, 2008, 14 pp.

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9. ACI Committee 506, "Guide for Specifying Underground Shotcrete (ACI 506.5R-09 (Reapproved 2016))," American Concrete Institute, Farmington Hills, MI, 2009, 52 pp.

10. ACI Committee 506, "Visual Shotcrete Core Quality Evaluation TechNote (ACI 506.6T-17)," American Concrete Institute, Farmington Hills, MI, 2017, 4 pp.

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Note: Additional information on the ASTM standards and IBC codes discussed in this article can be found at **www.astm.org** and **www.iccsafe.org**, respectively.

Selected for reader interest by the editors.

Charles Hanskat, *FACI, is the Executive Director of the American Shotcrete Association. He is a member of ACI Committees 301, Specifications for Structural Concrete; 350, Environmental Engineering Concrete Structures; 371, Elevated Tanks with Concrete Pedestals; 372, Tanks Wrapped with Wire or Strand; 376, Concrete Structures for Refrigerated Liquefied Gas Containment; and 506, Shotcreting; and Joint ACI-ASCE Committee 334, Concrete Shell Design and Construction. Hanskat received his BS and MS in civil engineering from the University of Florida, Gainesville, FL.*

ACI Honorary Member and ACI Past President ***Terence C. Holland*** *is a Consulting Engineer with Concrete.Terry. LLC, Auburn Township, OH. He is Chair of ACI Subcommittee 318-A, General, Concrete, and Construction, and a member of ACI Committee 318, Structural Concrete Building Code.*

Bruce A. Suprenant, *FACI, is the Technical Director of the American Society of Concrete Contractors. He is a member of ACI Committees 134, Concrete Constructability; 302, Construction of Concrete Floors; and 318, Structural Concrete Building Code; and Joint ACI-ASCC Committee 117, Tolerances. Suprenant's honors include the 2013 ACI Certification Award, the 2011 ACI Construction Award, and the 2010 ACI Roger H. Corbetta Concrete Constructor Award.*

Position Statement #2
ASA Underground Committee

american shotcrete association

Spraying Shotcrete on Synthetic Sheet Waterproofing Membranes

INTRODUCTION

Applying shotcrete for final linings against synthetic sheet waterproofing membranes has become more common in underground projects. The sprayed shotcrete is propelled at high velocity against the membrane and the dynamic energy consolidates the plastic shotcrete in place. However, the smooth surface and potential pillowing or vibrating of the waterproofing membrane poses a challenge compared to a shotcrete application against a stiff and rough surface.

The use of shotcrete final linings in underground applications is a standard placement technique. However, improper application of shotcrete against waterproofing membrane in a double shell system, with a separate temporary lining at the extrados and the final lining at the intrados of the membrane, can lead to poor-quality shotcrete due to delamination and voids, and produce local or large-scale fallouts, and can be the subject of technical disputes about cause and effect responsibilities.

This position paper discusses the basic elements of the adhesion of overhead and vertical shotcrete on a waterproofing membrane, the proper application techniques, and emphasizes the use of mockups. This position paper also provides recommendations for contractors and owners, from ASA's perspective, on how to properly apply, specify, and inspect shotcrete applied against waterproofing membranes.

ADHESION OF SHOTCRETE ON WATERPROOFING MEMBRANES

The phase immediately after application, when the shotcrete is still in a plastic state and has not gained any significant strength prior to the initial set, is referred to as "plastic shotcrete." The strength development starts after the initial and final set.[1,2] One of the major forces supporting the shotcrete against fallout, especially if applied overhead, is the adhesion of the shotcrete to the substrate.[2] If shotcrete is applied against a waterproofing membrane, the plastic shotcrete adheres to the membrane. However, because the membrane on the extrados is not directly applied to the initial lining over the entire area, the membrane cannot directly transfer the forces from the shotcrete weight into the initial lining. Adhesive forces of the plastic shotcrete can only be transferred into the initial lining at the fixation points of the membrane or where the membrane is supported by a self-supporting reinforcing bar cage.

REINFORCEMENT AND LATTICE GIRDERS

To avoid fallouts, plastic shotcrete must be supported by other means than the adhesion of the plastic shotcrete against the membrane. If the final lining is reinforced by reinforcing bar or welded wire fabric, the weight of the shotcrete is typically supported by the reinforcement. The reinforcement, on the other hand, is either suspended from anchors or is self-supporting, typically using lattice girders. In both scenarios, adhesion to the membrane is not required to keep the plastic shotcrete in place.

If the structural reinforcement bar is replaced with fiber-reinforced shotcrete, the plastic shotcrete is not supported by the reinforcement bar anymore. Despite the fact, that the reinforcement bar is not structurally required, a light reinforcement, suspended from anchors, might still be required to hold the shotcrete in place and as a support to potentially push the waterproofing membrane against the substrate. Alternatively, lattice girders are used and embedded with shotcrete first; as soon as the shotcrete around the lattice girders sets, the bay between two adjacent lattice girders can be filled, with the shotcrete in the bay bridging between the two lattice girders.

Spraying steel fiber-reinforced shotcrete does not damage or puncture the membrane because the forces acting on the fiber are not strong enough to push the fiber into the membrane and typically the fibers tend to orient parallel to the membrane on impact.

INSTALLATION OF WATERPROOFING SYNTHETIC SHEET MEMBRANES

Most waterproofing membranes are installed in sheets and anchored back in a 5 ft (1.5 m) or more spacing. However, if thicker shotcrete placement is envisioned, the spacing of the anchors may need to be reduced to carry a heavier load. Despite the fact, that the weight of the shotcrete is supported by other means, the installation of shotcrete on the waterproofing membrane is more challenging than in a poured concrete application. So-called "pillowing" of the membrane (a trapped air or water pocket or unwanted undulation underneath the waterproofing preventing the proper filling of materials) between fixation points must be avoided. Otherwise, the adhered shotcrete might rip the membrane. If hydrostatic water pressure builds up behind the membrane, the water pressure may further push the membrane in. The buildup of water pressure behind the membrane during the final lining installation must, therefore, be avoided by adequate water control measures. Pretreatment with injection (epoxy, polyurethane, or other chemicals) to minimize the hydrostatic water pressure may be required prior to installation of the waterproof membrane.

If the membrane is loosely spanning between adjacent fixation points, either because they are too far apart relative to the curvature of the arch or due to too-large outward waviness of the initial lining, the membrane may vibrate and prevent shotcrete adhesion during or immediately after application and cause increased rebound. Excessive spanning of the membrane must, therefore, be avoided.

The maximum spacing of the fixation points must be designed properly and should be tested in a mockup. The initial lining needs to be inspected before the waterproofing membrane installation, including but not limited to pillowing and spanning, before the shotcrete installation.

Distancers installed on the extrados reinforcement layer and the lattice girder provide a suitable means to avoid local pillowing and spanning.

PVC waterproofing membranes are more flexible compared to stiffer HDPE membranes. If rounded shapes prevail, HDPE membranes potentially have a higher risk of pillowing compared to PVC waterproofing membranes.

PROPER SPRAYING OF SHOTCRETE OVERHEAD

In general, shotcrete placement should start by spraying the base of the structure and continuing upwards and into the previously placed material, oscillating from one side to the other while moving up. This technique is also referred to as "bottom-up." Once shotcrete is placed at approximately 2 and 10 on a clock, the placement technique should change to using the anchor to anchor method with shotcrete placement in layers.[2]

The shooting should generally start at the load-bearing members (lattice girder or anchors), followed by bridging and material buildup in multiple passes between the load-bearing members. Overhead application (above springline) should always start from the bottom and work its way up continuously.[2]

If lattice girders are used, the lattice girders should be embedded with shotcrete first over the entire arch starting from the bottom. After two adjacent lattice girders have been properly embedded, the bay between adjacent embedded lattice girders can be sprayed from the bottom up. Depending on the total thickness of the lining, several passes may be required until the full shotcrete thickness is achieved. A sufficient time lag between each pass allows the previous pass to set and develop strength, mitigating the risk for fallout.[2] It is important to conduct preconstruction trial shotcrete placement and determine the acceptable time between each pass.

If the reinforcement cage is suspended from anchors, the area around the anchors should be embedded first, followed by bridging between adjacent anchors, preferably from the bottom up in a similar fashion to the lattice embedment girder process described earlier.[2]

If fiber-reinforced shotcrete is used, the use of lattice girders and a light reinforcement installed against the waterproofing membrane should be considered. The spraying process then follows the steps outlined previously. If neither reinforcement and lattice girders or anchors are used, the plastic shotcrete is suspended from the fixation points of the waterproofing only. The spacing of the fixation points must be reduced accordingly. Producing high-quality shotcrete under these conditions is a challenge and requires a tightened quality control process and a highly skilled nozzleman. In this case, it is recommended to build a buttress starting in the bench until the lining becomes slightly overhanging. Above springline, stripes of arching shotcrete should be produced first, followed by the closing of the bay areas between the stripes (similar to the approach with lattice girders). This is also referred to as "ribbon shooting."

In general, pillowing of the membrane as well as spanning distances between fixation points needs to be minimized in either case prior to the start of shotcreting.

Higher rebound, compared to spraying on a stiff and rough surface of the ground, is to be expected when spraying on waterproofing membranes.

The use of accelerator, especially when spraying overhead, is recommended following the manufacturer's guidelines.

MOCKUP

Following the ACI 506 guidelines, preconstruction testing and production of a mockup is strongly recommended.[3-5] The mockup should reflect the project-specific waterproofing and reinforcement conditions and mimic the on-site logistical and atmospheric conditions to reflect the expected placement conditions. It is not unusual to have several mockup trials to optimize the system and prove the envisioned concept works. In addition, the mockup allows the nozzleman to train under project-specific conditions.

RECOMMENDATIONS FOR THE CONTRACTOR

There is typically a contractual interface between the waterproofing installer and the shotcrete contractor and it can also include an interface with the reinforcing bar installer. To ensure quality and avoid deficiencies, these interfaces and handover requirements should be inspected and documented in detail by the shotcrete contractor. This includes but is not limited to smoothness criteria and conditions of the initial lining, pillowing or spanning of the membrane, water control measures, sufficient and properly placed membrane fixations and anchors, welding and potential damages of the membrane, and proper reinforcement and lattice girder installation.

Shotcreting should be tested on a mockup mimicking the project-specific installation of the waterproofing membrane the reinforcement and lattice girder installation.

The shotcrete nozzlemen should be ACI certified, experienced, skilled, and specifically briefed and trained for the installation of shotcrete against a waterproofing membrane. Prior to the application, nozzleman should be qualified for the project by shooting a mockup section with the waterproofing membrane. Proper shooting procedures and application sequence should be laid out in writing in the work plan and tested during the preconstruction mockup construction.

RECOMMENDATIONS FOR THE OWNER

The owner should provide a design reflecting the specific challenges for a final lining applied on a waterproofing membrane. Minimum key criteria need to be specified such as smoothness criteria, fixation and anchor spacing, reinforcement suspension or support, water control, and shotcrete specification following the applicable ACI 506 guidelines.[3-5]

A key element is the preconstruction testing and the project-specific mockups, which should be mandatory and in accordance with the ACI 506 guidelines.[3-5] The mockup should be saw-cut to clearly identify any delamination or defective shotcrete. The owner should not allow the start of the works until the contractor has proven that the contractor's means and methods and procedures can provide the envisioned quality of shotcrete.

In addition, the owner should focus on the inspection of the installation of the waterproofing membrane prior to the shotcrete installation to verify it has been placed correctly and then to inspect the shotcrete application.

CONCLUSION

Installation of shotcrete final linings is an efficient construction method that saves both time and cost. However, the installation of shotcrete on waterproofing membranes in underground applications is challenging.

The owner and contractor should face and meet the expected challenges prior to the start of construction. Experienced staff on either side are required for the successful execution of the project.

This position paper provides recommendations for a general approach to spraying shotcrete on synthetic sheet waterproofing membranes.

Acknowledgments

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Curing of Shotcrete for Swimming Pools

Shotcrete for swimming pools and other water containment structures such as aquatic parks and lazy rivers present unique complexities in curing and protection. As with all concrete, proper curing improves the overall gain of strength-related properties and reduces the overall amount and size of concrete cracking near the surface. However, for swimming pools, proper curing influences watertightness, long-term durability, and facilitates the bond and finishing ability of subsequent-applied cementitious finish coatings.

'Curing' is a method of maintaining adequate moisture within the concrete material nearest to the surface to ensure ongoing hydration of the cementitious binder. ACI 308R-16, "Guide to External Curing of Concrete," notes that surface exposure to 90% or less relative humidity can suspend hydration of cement at early ages. Thus, unless relative humidity is maintained above 90%, deliberate action must be taken, such as misting, soaking, or covering of the surface to maintain high humidity levels and conditions that allow the surface to hydrate at a similar rate to that of the inner matrix of the shotcrete.

Refer to ACI 506R, "Guide to Shotcrete," for additional curing methods. Typically, the effective zone for curing of concrete can reach depths between 1/4 and 3/4 in. (6 and 19 mm) from the outer surface depending on the finish texture and the permeability of the material. Although external curing does not penetrate deep enough to supply moisture to the inner matrix, maintaining a high humidity at the surface reduces the rate at which the inner-matrix water exits the system. Maintaining a similar moisture content and temperature between the outer surface and the inner matrix of the material promotes uniform hydration and lessens cracking associated with moisture and temperature gradients.

'Hydration' is the chemical reaction that converts the cementitious powder materials and water into a rigid structural material, or binder. In general, with sufficient moisture present, approximately 70% of cement hydration takes place in the first 7 days, and approximately 85% of cement hydration takes place in the first 28 days. The remaining unhydrated cement will continue to hydrate for many years after placement if moisture is present.

Minimizing Moisture and Temperature Gradients

The primary goal of curing is to maintain the moisture and temperature of the surface to levels that are similar to the interior of the shotcrete. Significant temperature or moisture gradients between the outer surface and the interior of shotcrete can result in cracking and a weaker, less-durable surface. Maintaining the temperature and sufficient moisture at the surface allows for a similar development of hydration and strength-gain properties to that of the interior of the shotcrete. A unique aspect of shotcrete in a water-submersion environment is that often, any shortfall in physical strength is quickly recovered subsequent to submersion, assuming sufficient cementitious material is present.

When a shotcrete cylinder or core meets or exceeds its required compressive strength (f_c'), a sufficient amount of cement has hydrated to achieve this strength. However, such testing may not adequately qualify the condition, strength, or durability of the outer surface. The quality of the outer surface can be weak or compromised, yet have little effect on strength test results based on cylinders or cores. Adherence to a proven curing method ensures the development of necessary outer-surface properties that directly impact the overall watertightness of shotcrete and the application and performance of a subsequently-applied cementitious finish coating.

Curing Considerations

ACI and ASA typically require that curing remains in place for a minimum of 7 days, or until at least 70% of the specified 28-day compressive strength (f_c') is achieved. It has been shown that extending wet curing from 3 days to 7 days can result in a 10 to 20% reduction in shrinkage cracking at the outer surface (the curing-affected zone). Prolonged wet curing significantly increases abrasion resistance (increases upper-surface strength) and significantly reduces surface permeability and absorption capacity.

For shotcrete swimming pool structures that are to receive a cementitious finish coating, ACI Committee 524, Plastering, and the National Plasterers Council (NPC) recommend that moist curing be continued for 28 days.

Ideally, the first 7 days should be soaked more frequently. It is recommended to soak the surface from three to five times per day (the more the better) initially, dependent upon the climate or region of the country. This is typically done by spraying water onto the shotcrete surface with a garden hose. Thereafter, it is recommended to wet all exposed surfaces at least once per day.

Wet curing for 28 days drastically reduces shotcrete's absorptive capacity. This is due to discontinued capillaries and carbonation of the surface. In some cases, well over a 50% reduction in absorptive capacity of the substrate is reported. Reducing shotcrete-absorptive capacity (capillary suction) also reduces shrinkage cracking. Reducing absorptive capacity also allows increased control of the subsequently-applied finish coating application by: creating a more uniform absorption rate across the surface of the shotcrete; extending the period of time available to physically force the finish coating material into the rough darby-cut shotcrete with minor surface depressions to achieve a good bond; and extending the time that mix water remains within the coating, enhancing overall finishability.

RECOMMENDED CURING

Immediately after finishing, keep shotcrete continuously moist for at least 7 days by soaking the surface three to five times daily or more. Thereafter, continue water curing at least once a day from day 7 to day 28. Wet periodically thereafter, one to two times per week, until the interior finish coating has been applied, and the swimming pool is filled with water.

Alternative curing methods have been employed to maintain surface moisture, such as covering the shotcrete with absorptive mat or fabric, sand or other covering, and keeping continuously wet; or covering the shotcrete with polyethylene sheeting of at least 4 mil thickness to prevent moisture loss. Curing compounds, if used, must be removed prior to applying subsequent coatings to ensure that an adequate bond can be achieved between the coating and the shotcrete.

The shotcrete should not be allowed to freeze until it has reached a minimum compressive strength. Generally, shotcrete that has reached 500 psi (3.5 MPa) before freezing takes place will not be damaged by freezing. When the temperature of shotcrete rises above 40°F (4°C), the hydration reaction will resume, and further develop strength. In general, shotcreting operations should be stopped when the anticipated 24-hour (daily) average ambient temperature falls below 40°F unless cold weather concrete measures are taken such as those mentioned in ACI 306R. In a hot-weather environment, the problems encountered with wet-mix shotcrete are the same as for form-and-pour concrete: increased water demand, increased rate of slump loss, rapid setting, and difficulty in regulating the entrained air content. For dry-mix and wet-mix shotcrete, the finishing operations, if any, should proceed as rapidly as the shotcrete condition allows. Curing should also start as soon as possible.

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Position Statements

ASA has produced position statements on the best practices for proper shotcrete placement. To date, seven position statements from our Pool & Recreational Shotcrete Committee, two from our Underground Committee, and one from our Board of Direction have been issued. These statements have also been published in *Shotcrete* magazine.

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Common Test Panel Mistakes

By Dennis Bittner

Frequently, shotcrete contractors are required to shoot test panels at the beginning as well as throughout projects. Several tests are performed from these panels; however, compressive strength testing is the most common. This article will primarily address compressive strength testing. At some point, every contractor has missed a required break strength on a core extracted from one of their panels. Frequently, those bad results are not caused by bad material or poor workmanship. They are caused by poor test panel handling and improperly performed test standards. Often, the causes of those bad test results could have been easily avoided. Let's discuss some of the more common test panel mistakes witnessed in the field.

ASTM Standards

There are two ASTM standards that govern the panels: ASTM C1140/C1140M, "Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels," and ASTM C1604/C1604M, "Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete." ASTM C1140/C1140M covers producing the test panels, and ASTM C1604/C1604M covers extracting and testing cores from the panels. Every shotcrete contractor should be extremely familiar with both standards.

Fig. 1: Field test panel being properly gunned on site

The first step is to get into the right mindset. Contractors often have the attitude of "it's just a test panel, it's not that important, it's the actual structure that matters." It should be noted that panel is how you will be evaluated, and ultimately, how you will be paid. The material needs to be placed in the panels no differently than it is placed on the project. That means using the same equipment, techniques, and most importantly the care that are used on the structure. Do not take shooting test panels lightly.

Proper Panel Construction

Panels need to be constructed on 3/4 in. (19 mm) plywood—any thinner and the panel will bow during the application process. It is not recommended to build panels any larger than necessary. Additional size means additional weight and makes the panels more difficult to handle. A 2 x 2 ft (0.6 x 0.6 m) panel will yield nine cores or three breaks, a break strength being the average of three cores. If more cores are necessary, it is recommended to shoot two smaller panels rather than one larger panel. Occasionally, the contractor is required to shoot mockup panels containing reinforcing bar for visual grading. If this is the case, separate panels not containing reinforcing bar should be constructed for compressive strength testing. Compressive samples should not be taken from panels containing reinforcing bar. Coring and cutting through the reinforcing bar put excessive movement and vibration through the shotcrete and can result in microfractures forming throughout the panel.

Proper Handling of Panels

Additionally, panels need to be cured as soon as possible after shooting. Ideally, panels should be stored in a moist room. However, moist rooms generally are not located on jobsites, and it is difficult to move freshly shot panels without damaging them. When a moist room is not practical, panels should be covered and wrapped, and a spray-applied curing agent or wet cure should be used. Panels

Errores Comunes en el Panel de Prueba

Por Dennis Bittner

Con frecuencia, los contratistas de concreto lanzado tienen que lanzar en paneles de prueba tanto al principio como a lo largo de los proyectos. Se realizan varios ensayos desde estos paneles; sin embargo, los ensayos de resistencia a la compresión son las más comunes. Este artículo abordará principalmente los ensayos de resistencia a la compresión. En algún momento, cada contratista ha perdido una resistencia a la rotura requerida en un núcleo extraído de uno de sus paneles. Frecuentemente, esos malos resultados no son causados por un mal material o una mala mano de obra. Son causadas por un manejo deficiente del panel de prueba y por estándares de ensayo realizados incorrectamente. A menudo, las causas de esos malos resultados de las pruebas podrían haberse evitado fácilmente. Hablemos de algunos de los errores más comunes de los paneles de prueba que se observan en el campo.

ESTÁNDARES ASTM

Existen dos normas ASTM que rigen los paneles: ASTM C1140/C1140M, Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels, y ASTM C1604/C1604M, Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete. ASTM C1140/C1140M cubre la producción de los paneles de prueba, y ASTM C1604/C1604M cubre la extracción y ensayo de núcleos de los paneles. Cada contratista de concreto lanzado debe estar muy familiarizado con ambos estándares.

El primer paso es entrar en la mentalidad correcta. Los contratistas a menudo tienen la actitud de "es sólo un panel de prueba, no es tan importante, lo que importa es la estructura real". Debe tenerse en cuenta que el panel es la forma en que se le evaluará y, en última instancia, la forma en que se le pagará. El material debe colocarse en los paneles de la misma manera que se coloca en el proyecto. Esto significa utilizar el mismo equipo, las mismas técnicas y, lo que es más importante, el mismo cuidado que se utiliza en la estructura. No tome el colocado de los paneles de prueba a la ligera.

CONSTRUCCIÓN ADECUADA DEL PANEL

Los paneles necesitan ser construidos en 3/4 pulg. (19 mm) de madera contrachapada. Un poco más delgado y el panel se pandeará durante el proceso de aplicación. No se recomienda construir paneles más grandes de lo necesario. Un tamaño adicional significa un peso adicional y hace que los paneles sean más difíciles de manipular. Un panel de 2 x 2 (0.6 x 0.6 m) pies producirá nueve núcleos o tres roturas, siendo la resistencia a la rotura el promedio de tres núcleos. Si se necesitan más núcleos, se recomienda colocar dos paneles más pequeños en lugar de uno más grande. Ocasionalmente, el contratista está obligado colocar paneles de maquetas que contengan barras de refuerzo para la clasificación visual. Si este es el caso, se deben construir paneles separados que no contengan barras de refuerzo para el ensayo de resistencia a la compresión. No se deben tomar muestras de compresión de los paneles que contienen barras de refuerzo. La extracción de núcleos y el corte a través de la barra de refuerzo provocan un movimiento y vibración excesivo a través del concreto lanzado y pueden dar lugar a la formación de microfracturas en todo el panel.

MANEJO ADECUADO DE LOS PANELES

Además, los paneles deben curarse lo antes posible después de la colocación. Lo ideal es que los paneles se almacenen en un cuarto húmedo. Sin embargo, los cuartos húmedos generalmente no están ubicados en los sitios de trabajo, y es difícil mover los paneles recién colocados sin dañarlos. Cuando un cuarto húmedo no es práctico, los paneles deben ser cubiertos y envueltos, y se debe

Fig. 1: Panel de prueba de campo debidamente colocado en el sitio

should not be exposed to direct sunlight, as this will dry them out prematurely and can cause early-age plastic shrinkage cracking. Once completed, panels should not be moved any more than necessary. Every time a panel is moved when the concrete is relatively green is an opportunity for microfractures to form or other damage to occur. Do not strip the forms from the panel. This exposes more of the shotcrete to air and causes evaporation and, again, can lead to more potential for early-age plastic shrinkage cracking. Additionally, with no reinforcement in the panel, the wooden form becomes the reinforcement. Once the wood is stripped, you are left with a sizeable, heavy piece of unreinforced shotcrete. The sample will then bow and flex every time it is moved and this can physically damage the panel. The best policy is to shoot it, cure it, protect it, and then leave untouched until you are ready to extract cores.

Fig. 2: Specimen that has not been cut to 90 degrees in a break machine

Fig. 3: Type of break indicative of a point load as a result of a core that has not been cut to 90 degrees

EXTRACTING PANEL CORES

Once the panel has reached a specified age, it is time to extract cores for compressive testing. Great care must be taken when extracting cores. Per ASTM C1140/C1140M, specimens should be extracted no more than 2 hours before testing. If you are required to perform 7- and 28-day tests, take only the 7-day cores at the 7-day mark. Come back at 28 days for the 28-day specimens—do not extract the 28-day specimens at the 7-day mark. These specimens are relatively small in size and dry out quickly once removed from the panel, resulting in low breaks. Also, early-age testing of shotcrete can be difficult. Occasionally, a 1-day strength is required. Because the material is still very green at that point, extra care must be taken when coring the panel. Typically, an accelerator is used in the mixture when 1-day breaks are required. Cores with a minimum diameter of 3 in. (75 mm) should not be taken from the area within the depth of the panel plus 1 in. (25 mm) from the edges of the panel. For example, if your panel is 3.5 in. (88.9 mm) deep, then you should avoid coring within 4.5 in. (114 mm) from the panel edges to avoid sampling trapped rebound.

It is important that the right drill and bit are chosen to take cores. A seated or saddled drill must be used. Do not use a handheld drill. Diamond bits must be used. It is extremely important that the bit goes straight down at a 90-degree angle and does not chatter. Should the bit chatter or any other problem arise, back off and start a completely new core—do not continue to drill in your current location on the panel. Any type of irregular movement from the bit can damage the specimen, and that specimen needs to be abandoned. Once extracted, verify that the samples are at 90-degree angles. When a sample does not sit straight up and down, the compression testing machine will exert uneven pressure on the sample. If the ends of the cores do not conform to the perpendicularity and planeness requirements of ASTM C39/C39M, they should be sawn or ground to meet those requirements or capped in accordance with ASTM Practice C617. This point loading frequently results in the corners of the cylinder breaking first when put under stress and not being representative of the strength across the full cross section of the core. Additionally, if an edge of the sample is not flat and level, it needs to be saw-cut and made flat. It is a misconception that compressive testing machines are self-leveling. They will match the angle of the top of the core—they will not level the core. Cores with bearing surfaces that are out of level will also generate lower break strengths due to point loading.

It is recommended that cores have a minimum diameter of 3 in. Remember, core bits are measured by the outside dimension of the bit, so subtract 1/4 in. (6 mm) to usar un agente de curado aplicado por aspersión o curado húmedo. Los paneles no deben exponerse a la luz directa del sol, ya que esto los secará prematuramente y puede causar agrietamiento por contracción plástica a una edad temprana. Una vez terminados, los paneles no deben moverse más de lo necesario. Cada vez que se mueve un panel cuando el concreto está relativamente verde, existe la posibilidad de que se formen microfracturas u otros daños. No retire las cimbras del panel. Esto expone más del concreto lanzado al aire y provoca evaporación y, de nuevo, puede llevar a un mayor potencial de agrietamiento por contracción plástica a una edad temprana. Además, sin refuerzo en el panel, la cimbra de madera se convierte en el refuerzo. Una vez que la madera es descortezada, se queda con un trozo considerable y pesado de concreto lanzado sin refuerzo. La muestra se pandeará y se flexionará cada vez que se mueva y esto puede dañar físicamente el panel. La mejor política es lanzarlo, curarlo, protegerlo y luego dejarlo inalterado hasta que esté listo para extraer los núcleos.

EXTRACCIÓN DE NÚCLEOS DE PANEL

Una vez que el panel ha alcanzado una edad específica, es el momento de extraer los núcleos para realizar ensayos de compresión. Se debe tener mucho cuidado al extraer núcleos. Según la norma ASTM C1140/C1140M, las muestras deben extraerse no más de 2 horas antes del ensayo. Si se le requiere realizar pruebas de 7 y 28 días, tome solo los núcleos de 7 días en el plazo de 7 días. Regrese a los 28 días para los especímenes de 28 días - no extraiga los especímenes de 28 días a los 7 días. Estos especímenes son relativamente pequeños en tamaño y se secan rápidamente una vez retirados del panel, lo que resulta en roturas bajas. Además, los ensayos a temprana edad del concreto lanzado pueden ser difíciles. Ocasionalmente, se requiere una resistencia de 1 día. Debido a que el material sigue siendo muy verde en ese momento, se debe tener especial cuidado al extraer el núcleo del panel. Típicamente, se utiliza un acelerador en la mezcla cuando se requieren descansos de un día. Núcleos con un diámetro mínimo de 3 pulg. (75 mm) no debe tomarse del área dentro de la profundidad del panel más 1 pulg. (25 mm) de los bordes del panel. Si su panel es de 3.5 pulg. (88.9 mm) de profundidad, entonces debe evitar la extracción en un radio de 4.5 pulg. (114 mm) de los bordes del panel para evitar el rebote atrapado de la muestra.

Es importante que se escoja el taladro y la broca correctos para tomar los núcleos. Se debe usar un taladro sentado o ensillado. No utilice un taladro de mano. Se deben usar brocas de diamante. Es extremadamente importante que la broca descienda en un ángulo de 90 grados y no parlotee. Si la vibración de la broca o cualquier otro problema surge, retroceda y comience un núcleo completamente nuevo; no continúe perforando en su ubicación actual en el panel. Cualquier tipo de movimiento irregular de la broca puede dañar el espécimen, y ese espécimen necesita ser abandonado. Una vez extraídos, verifique que las muestras estén en ángulos de 90 grados. Cuando una muestra no se asienta hacia arriba y hacia abajo, la máquina de ensayo de compresión ejercerá una presión desigual sobre la muestra. Si los extremos de los núcleos no cumplen con los requisitos de perpendicularidad y planitud de la norma ASTM C39/C39M, deben ser aserrados o rectificados para cumplir con dichos requisitos o tapados de acuerdo con la norma ASTM C617. Este punto de carga frecuentemente resulta en que las esquinas del cilindro se rompen primero cuando se someten a esfuerzo y no son representativas de la resistencia a lo largo de toda la sección transversal del núcleo. Además, si un borde de la muestra no es plano y nivelado, debe ser cortado con sierra y aplanado. Es un concepto erróneo que las máquinas de ensayo de compresión son autoniveladoras. Coinciden con el ángulo de la parte superior del núcleo: no nivelan el núcleo. Los núcleos con superficies de aplastamiento que están fuera de nivel también generarán menores resistencias a la rotura debido a la carga puntual.

Se recomienda que los núcleos tengan un diámetro mínimo de 76 mm (3 pulg.) Recuerde, las brocas de núcleo se miden por la dimensión exterior de la broca, así que reste

Fig. 2: Muestra que no ha sido cortada a 90 grados en una máquina de rotura

Fig. 3: Tipo de rotura que indica una carga puntual como resultado de un núcleo que no ha sido cortado a 90 grados

determine the core size. A 3 in. core requires a 3-1/4 in. (83 mm) bit. On some jobsites, panels are shot to a depth of 6 in. (152 mm). Using a 3 x 6 in. sample, we have a length-to-diameter ratio of 2:1. In that case, the break strength is directly recorded. In many cases, panels are shot to a depth of less than 6 in., resulting in a different length-to-diameter ratio. When this happens, a correction factor, located in ASTM C1604/C1604M, Section 8.8.1, must be used. For example, a core is 3 x 3.75 in. (75 x 95 mm), giving a length-to-diameter ratio of 1.25. The correction factor is 0.93. So, if a core of that size has a break at 10,000 psi (69 MPa), we apply the 0.93 correction factor and the actual recorded break is 9300 psi (64 MPa).

Testing Lab

Finally, do not assume your testing lab is performing all tests correctly. Many testing labs are unfamiliar with shotcrete, and therefore unfamiliar with some of the subtle differences between obtaining and testing shotcrete cores versus concrete cylinders. It is a good practice to visit the lab you intend to use before testing begins. Review ASTM C1604/C1604M and ASTM C1140/C1140M. If they are storing the panels at the lab, review their curing procedures.

Make sure the testing lab understands not to take cores from the edges of the panels, and make sure if a strength correction factor is used, it is the correct one. If they are performing the core extraction, review the equipment needs and coring procedures. Verify the core ends are truly perpendicular to the axis before testing.

Conclusions

Testing errors can cause a lot of avoidable grief, anger, and frustration for everyone. So, in the event of a low compressive strength break, review the panel production, protection, and curing procedures as well as the testing methods to identify any possible errors before moving on to blame either material or workmanship issues. Always take adequate time, thought, and care to get accurate panel test results. This is often how your work is graded on the project and is often tied to getting paid. The small investment in time and effort to make panel production and testing truly representative of your quality shotcrete work will make your projects more productive, higher quality, and ultimately more profitable in the future.

***Dennis Bittner** is the National Sales Manager–Infrastructure for The QUIKRETE Companies. He has been involved in both wet- and dry-mix process projects in multiple arenas of shotcrete construction, with an emphasis on bridge and tunnel projects for state departments of transportation and the rail industry. In addition to being an ASA member, Bittner served on the ASA Board of Directors. He can be reached at dbittner@quikrete.com.*

1/4 pulg. (6 mm) para determinar el tamaño del núcleo. Un núcleo de 3 pulg requiere una broca de 83 mm (3-1/4 pulg.). En algunas obras, los paneles se colocan a una profundidad de 6 pulg. (152 mm). Usando una muestra de 3 x 6 pulgadas, tenemos una relación longitud-diámetro de 2:1. En ese caso, la resistencia a la rotura se registra directamente. En muchos casos, los paneles se colocan a una profundidad inferior a 6 pulg., lo que resulta en una relación de longitud a diámetro diferente. Cuando esto sucede, se debe usar un factor de corrección, ubicado en ASTM C1604/C1604M Sección 8.8.1. Por ejemplo, un núcleo es de 3 x 3.75 in. (75 x 95 mm), lo que da una relación longitud/diámetro de 1.25. El factor de corrección es 0.93. Por lo tanto, si un núcleo de ese tamaño tiene una ruptura a 10.000 psi (69 MPa), aplicamos el factor de corrección de 0.93 y la ruptura real registrada es de 9300 psi (64 MPa).

LABORATORIO DE PRUEBAS

Finalmente, no asuma que su laboratorio de pruebas está realizando todas las pruebas correctamente. Muchos laboratorios de pruebas no están familiarizados con el concreto lanzado y, por lo tanto, no están familiarizados con algunas de las sutiles diferencias entre la obtención y el ensayo de núcleos de concreto lanzado frente a cilindros de concreto. Es una buena práctica visitar el laboratorio que desea utilizar antes de comenzar las pruebas. Revise ASTM C1604/C1604M y ASTM C1140/C1140M. Si están almacenando los paneles en el laboratorio, revise sus procedimientos de curado.

Asegúrese de que el laboratorio de pruebas comprenda que no debe tomar núcleos de los bordes de los paneles, y asegúrese de que, si se utiliza un factor de corrección de la resistencia, sea el correcto. Si están realizando la extracción del núcleo, revise las necesidades del equipo y los procedimientos de extracción. Verifique que los extremos del núcleo sean verdaderamente perpendiculares al eje antes de realizar la prueba.

CONCLUSIONES

Los errores en las pruebas pueden causar mucho dolor, enojo y frustración evitables para todos. Por lo tanto, en caso de una rotura de baja resistencia a la compresión, revise la producción del panel, la protección y los procedimientos de curado, así como los métodos de prueba para identificar cualquier posible error antes de pasar a culpar a los problemas de material o mano de obra. Siempre tómese el tiempo adecuado, piense y tenga cuidado para obtener resultados precisos de las pruebas de panel. Esta es a menudo la forma en que su trabajo se califica en el proyecto y a menudo está ligado a la obtención de un pago. La pequeña inversión en tiempo y esfuerzo para hacer que la producción de paneles y las pruebas sean verdaderamente representativas de su trabajo de calidad con concreto lanzado harán que sus proyectos sean más productivos, de mayor calidad y, en última instancia, más rentables en el futuro.

Dennis Bittner *es el Gerente Nacional de Ventas de Infraestructura para las Empresas QUIKRETE. Ha estado involucrado en proyectos de procesos de mezcla en húmedo y en seco en múltiples campos de la construcción de concreto lanzado, con énfasis en proyectos de puentes y túneles para los departamentos estatales de transporte y la industria ferroviaria. Además de ser miembro de la ASA, Bittner forma parte de la Junta Directiva de la ASA. Puede ser contactado en dbittner@quikrete.com.*

Improving Shotcrete Inspections

By Mark Bradford

Shotcrete is a placement method for concrete. Even though the shotcrete process is over 100 years old, it constantly evolves and today, it is a modern, cost-effective, and more sustainable method of concrete placement. Those of us who regularly shotcrete a variety of work will at times have inspections and therefore have to work with inspectors. Understanding the inspector's role as a safeguard or agent for the owner is important.

However, we often find dealing with inspectors can be a cumbersome part of our job. Knowing how to do something properly and being able to fully explain the means and methods of a specialized process (shotcrete) to someone who has little to no firsthand experience are two completely different animals.

ASA SHOTCRETE INSPECTOR EDUCATION AND ACI CERTIFICATION

ASA has been making great strides in developing resources for inspector education and also working with ACI on the creation of its inspector certification. ASA's education program is only a couple of years old and the ACI certification was recently launched in Fall 2019. It will take time for these resources to reach the majority of inspectors that may be involved with shotcrete projects. Thus, we contractors will often still have inspectors on our projects who are either ill-informed or uneducated about the shotcrete process.

AVOIDING POTENTIAL JOBSITE ISSUES

Outdated specifications are often cut and pasted into project plans and specifications. At times, boilerplate or typical/standard items will be integrated without any validity or relevance to the actual job or process. Disputes on jobsites may arise when an outdated or incorrect specification is coupled with an inspector with little to no experience with the shotcrete process who must enforce that specification. Though an experienced shotcrete contractor knows what is needed for quality, durable shotcrete placement, the inspector may try to enforce provisions that are not appropriate and can decrease the quality of the shotcreted concrete.

The best way to avoid potential jobsite issues is to plan ahead. Review all of the project plans and specifications prior to the job. When there are issues that may affect proper or efficient shotcrete placement, make them known to the specifier or owner as soon as possible. Hopefully, proper solutions to the issues can be developed prior to the contract phase.

SHOTCRETE RESOURCES

There are a multitude of resources and information available through ASA and ACI that can help specifiers create current and applicable specifications and details. This includes ASA 1-hour on-site seminars for specifiers, full-day seminars for shotcrete inspectors, answers to technical inquiries, the resources page on **www.shotcrete.org**, position statements, and technical sessions at ASA conventions. ACI Committee 506, Shotcreting, has many documents covering shotcrete including ACI 506.2, "Specification for

Shotcrete," providing the specifier an up-to-date mandatory specification that can be directly included in project documents by reference. ACI 506R-16, "Guide to Shotcrete," also has a wealth of information about shotcrete materials, equipment, crew responsibilities, placement techniques, curing, testing, and protection.

Contractors Must Be Knowledgeable and Prepared

I recently reviewed a contract document for a wet-mix shotcrete job that included only dry-mix-specific details, and no wet-mix-specific details. In this instance, because the job was still several months away, we had the time and ability to send RFI's to correct the situation before we arrived on the jobsite. But imagine if we had not reviewed the contract documents and showed up where the inspector was enforcing dry-mix provisions on our wet-mix placement. That would have been problematic from the first day on the job.

If for some reason, a project specification gets handed to you while the concrete truck is backing up to the pump, you must be ready to educate the inspector on the fly. Not only about proper procedures and the methodology behind them, but also about the concrete mixture design. This is where it is critically important that you as the contractor are knowledgeable, and able to relay the correct information quickly.

As a knowledgeable and experienced shotcrete contractor, you should have enough familiarity of mixture design to read and understand batch weights from the delivery ticket and compare them to the specified mixture design. Make sure that you are aware of the mixture design details to know how the concrete will behave and how the specifier is expecting the final concrete in-place to perform.

It is a necessity that the batch plant sends you batch weights for every truck. Batch weight tickets are the only way to know what materials are in the truck, as well as what you will be placing. Quality, ease of placement, and safety are key reasons for knowing the exact details of the concrete mixture being delivered to the jobsite.

An inspector may question the mixture design and the properties of the concrete. Most often, the first question will be about the slump and the second will be about the water-cementitious materials ratio (*w/cm*) of the mixture.

There are often specifications (or even building codes) that regulate slump even though it has limited, if any, true bearing on the in-place strength, quality, or durability of the concrete. You must be able to communicate that slump is only an indicator of workability and has little to no bearing on in-place strength as long as the specified *w/cm* is adhered to, and that if a mixture is too stiff, it will not properly encapsulate the reinforcing steel and can lead to safety issues due to plugged delivery lines. You must also be able to communicate that the slump at the truck and the slump at the nozzle can be quite different, especially when you are pumping long distances through a small-diameter delivery line. Slump loss can be a real issue.

One of the things that has made my life easier is to not show a value for the slump or a slump range when submitting mixture designs for approval. The lack of a specified value for slump that an inexperienced inspector may try to enforce allows the certified nozzleman to adjust the workability of the mixture as needed for proper placement without exceeding the desired *w/cm*. This is a key concept that all ACI certified nozzleman learn in the ASA nozzleman education.

Properly placed shotcrete needs to be viscous enough to "flow" around and encapsulate the reinforcing steel. Impact velocity, angle of impact, and higher paste content are a few of the things that allow for shotcreted concrete to flow while also stacking up well.

Another issue with slump revolves around the batch plant and the concrete truck driver. Sometimes the concrete is ordered at a specified slump and it will arrive very dry (low slump). The typical reason a driver may provide is "I saw the ticket said shotcrete, so I made sure that it was really dry." Getting concrete to arrive at a specified slump often can be a challenge that needs to be discussed with your concrete supplier prior to the concrete being transported.

Not too long ago, on a job in southern California, I had the opportunity to educate an inspector who really wanted to learn more about the shotcrete process. The experience of being able to walk him through the shotcrete process step by step from concrete mixture design, through placement, and curing was very rewarding for me, and hopefully him, too. The inspector was able to stand next to me during shooting while I verbalized what I was doing, and the reasoning behind it. He was very thankful for the time and the education.

Taking a few minutes to talk through the aspects of proper shotcrete placement and the reasons behind doing them with the inspector usually will go a long way towards a successful outcome for your job. Hopefully, we all (contractor, inspector, and owner) have the same goal of a high-quality, durable concrete in-place creating a long-lasting project for the owner.

Conclusions

I am very excited about the future of the ASA Inspector Education Program, and what it means for the future of shotcrete. The more people who are properly educated about the shotcrete process helps with not only the specifying, but the placement and inspection processes as well. The future of shotcrete is bright, and I'm excited to see all the amazing ways that shotcrete can be used.

ACI Certified Nozzleman ***Mark Bradford*** *is an ASA member who actively works as a nozzleman on numerous projects. He is COO of Spohn Ranch, Inc., which has specialized in skatepark construction using shotcrete worldwide since 1992.*

CanCrete Equipment Ltd.

CanCrete Equipment Ltd. (CanCrete) is a Canadian family-run business based out of Mississauga, ON, Canada, with a long history of supporting the shotcrete industry in the Greater Toronto Area. CanCrete focuses on anything that is required to move cementitious material from point A to point B, including concrete, shotcrete mixtures, grout, self-leveling, fireproofing, and epoxy. The company serves customers in markets from small-line pumping to high-rise placing equipment with equipment sales and rentals, parts and accessories sales, technical and engineering support, and equipment servicing.

CanCrete has the equipment that contractors need to pump or spray mixtures, such as concrete, epoxy coatings, fireproofing and insulation materials, and shotcrete. For these industries, CanCrete stocks hoses, pipes, clamps, elbows, reducers, reducing elbows, sponge balls, concrete cleaners, slick pack, pole guns, and much more at the Toronto warehouse. For customers preferring Original Equipment Manufacturer (OEM) parts, those are readily available for a variety of manufacturers.

BACKGROUND

Co-founded by husband and wife team Eric and Marcia Duiker in 2013, CanCrete acquired the Toronto location of Shotcrete Plus, a company that had primarily focused on the shotcrete industry and specialized in dry-mix shotcrete.

Eric was raised around concrete pumps. His father started in forming (both conventional and insulated concrete forms [ICF]) and eventually bought his first concrete pump as part of a natural progression to meet customer needs. Marcia's career began with P&G and then later Effem Foods; there, she focused on product supply. Meanwhile, Eric started his career working in Skyjack's engineering department and then later at an investment casting business located in Belleville, ON, Canada. The couple moved to the Greater Toronto Area in 2008 when Eric joined the family business.

The couple met at the University of Waterloo, Waterloo, ON, Canada, in 2001, when both individuals were pursuing engineering degrees. They married in 2005 and have three children.

In 2013, the Duikers were presented with the opportunity to purchase the Toronto location of Shotcrete Plus.

CanCrete quickly established itself in Ontario and has partnered with many of the major players in placing concrete in the Ontario market. The word "partner" is key to the company. It is a relationship maintained with both customers and suppliers to create mutually beneficial connections. This approach with customers has allowed the company to diversify the markets served and has paved the way for growth opportunities with suppliers including expansion into the Quebec and Maritimes provinces.

Fig. 1: CanCrete Equipment (pump make and model) on display at the 2019 Canadian Concrete Expo

Fig. 2: Eric and Marcia Duiker at CanCrete Equipment's head office and warehouse in Mississauga

With the distribution rights for the Putzmeister brand, the company initially focused on mortar/fireproofing equipment, along with shotcrete, small-line concrete pumping parts, and service. From there, the company expanded the equipment sales portion of its business by taking on boom pump sales and support in 2015.

CANCRETE SERVICES

Whether a client is purchasing a pump, renting a pump, or picking up a length of hose, the team fosters the relationship with ongoing support. The Mississauga shop is always ready for a seasonal service or an urgent repair; its factory-trained mechanics understand the urgency of minimizing downtime and are thorough in checking over equipment to ensure that it hits the jobsite running. CanCrete also supports its clients with on-site training, warehouse demonstrations, partnerships with material suppliers, and in-house training with manufacturers.

THE CANCRETE MISSION

The company's mission is "to be a leading supplier of pumping equipment, parts and associated repair in the Canadian industrial pumping market. We're customer focused and have thoroughly researched the products and parts we offer, so we are prepared to advise customers on what best suits their needs." Its experienced staff offers solutions to the concrete industry, be it through new or used equipment, parts, service, or simply providing advice when needed. CanCrete believes success comes when you really know, understand, and provide what customers value and need.

Leveraging decades of concrete forming and pumping experience within the family, CanCrete puts a large emphasis on ensuring that all employees gain significant "hands-on" on-site experience to equip them in supporting customers.

In 2017, CanCrete added a second location in Orangeville, ON, Canada. Since inception, the company has hired 15 staff who work out of Ontario and Quebec.

With a focus in recent years on product sourcing, CanCrete has fully stocked quality, fair-priced parts.

Fig. 3: CanCrete hosts an annual pump operator safety course at its Mississauga location

Besides being a Putzmiester dealer, CanCrete represents Graco mortar and fireproofing machines, the peristaltic Quikspray, the Chemgrout product line up, the Airplaco shotcrete and mortar portfolio, as well as IMER, Tovel and Multiquip mixing equipment. For fleet cleaning, CanCrete offers Back-set Platinum concrete dissolver, which has proven tried and true on its own rental fleet for many years.

The CanCrete team is ready to support you. Call CanCrete about your next project and the company will be glad to partner with you for a successful shoot or pour.

CANCRETE EQUIPMENT LTD.

TORONTO: 1810 Meyerside Drive, Mississauga
Phone: 416.749.2843
MONTREAL: 1855 Rue Cunard, Laval
Phone: 514.884.0076
ORANGEVILLE: 10 Coles Cres, Mono
Phone: 519.942.8844
Website: www.cancrete.ca
E-mail: sales@cancrete.ca

REVOLUTION GUNITE

Revolution Gunite provides services in the Southeast using the dry-mix shotcrete process for the swimming pool industry as well as for infrastructure and architectural work. Its current service area includes North Carolina, South Carolina, Virginia, West Virginia, and eastern Tennessee.

HISTORY

Clearwater Construction Group, Inc., the parent company to Revolution Gunite, started in 1998 building water features, fountains, and stone masonry. Over the course of 21 years, Clearwater has delved deep into all things water, from earthen ponds to swimming pools and commercial water features. In addition, the company has excelled in hardscape and general construction specialties, such as unit paving, concrete installation, stone fabrication, brick and block masonry, and residential and commercial construction.

Since 2006, Clearwater has concentrated its efforts on swimming pool construction and design, self-performing most aspects of the swimming pool construction process.

Along the way, Revolution Gunite was born with an aim to serve other pool contractors by providing top-notch dry-mix shotcrete services for pool construction.

Today, the company is partitioned and structured as follows:

- Clearwater provides design for architectural and engineering firms, pool contractors, and owners;
- Revolution Gunite performs dry-mix shotcrete for pool contractors, DOTs, municipalities, and general construction; and
- Revolution Pool Finishes, Licensed Pebble Tec applicators for interior pool finishes, providing the Pebble Tec product line.

PHILOSOPHY

The idea behind the "Revolution" is to bring an environment of change and integrity to the swimming pool industry with education and training with the end goal of better shotcrete placement. Never satisfied as pool contractors with the locally available shotcrete placement services, Revolution Gunite decided to use its industry knowledge and expertise to create a company that could satisfy the needs of the industry as well as raise the bar of quality. To do so, they employ a variety of techniques:

- Employ ACI-certified nozzlemen and nozzlemen-in-training;
- Continuous training of staff in the field as well as the classroom;
- Provide support to their builders with education opportunities and technical support;
- Use mobile volumetric batch trucks to allow for better metering of material for quality control and accurate placement quantities;
- Follow ACI guidelines for shotcrete placement; and
- Ongoing research and development to continuously improve placement techniques and mixture designs.

MISSION

Through service, knowledge, and integrity, Revolution Gunite strives to create added value for every customer.

Fig. 1: Mountain pool in North Carolina: (a) before; and (b) after

PROJECT HIGHLIGHTS

North Carolina Mountain Pool—2015 ASA Outstanding Shotcrete Project Award

This project is a highly technical perimeter overflow and vanishing-edge pool, cantilevered 8 ft (2.4 m) and suspended 50 ft (15 m) over the ground below. The edge is within 1/32 in. (1 mm) level all the way around and is an all-glass tile pool.

Bald Head Island

Using the dry-mix process allowed Revolution Gunite to serve a remote island resort with no bridges by transporting a portable cement silo, mobile batch trucks, cement tankers, and hundreds of tons of aggregates over barges in a narrow timeframe, dodging high winds and tidal shifts. This flexibility allowed Revolution Gunite to shoot three commercial pools in an extremely tight timeline to meet the pool contractor's and developer's deadlines.

Swamp Thing

With a very tight timeline, Revolution Gunite was able to shoot the shell for an indoor swamp on a movie set in 9 days. The project was over 18,000 ft^2 (1700 m^2). The entire floor was shot without reinforcing steel to accomodate the transitional use of this space. Instead, natural jute fibers for shrinkage mitigation and improved curing were used. Artists were hired to carve the "mud banks" and color was added to the dry-mix shotcrete per request of the studio. The entire swamp is watertight and designed to be torn out after the production.

Purlear Creek

With over 700 yd^3 (540 m^3), this project highlights the use of jute and hemp natural microfibers, as well as a slag/portland blended cement to create the unique properties this project demanded. Hand-carved concrete by on-staff artisans emulates natural rock in this mountainous setting.

Fig. 2: Bald Head Island project: (a) transportation of Revolution Gunite's trucks, equipment, and materials; and (b) construction on the island

Fig. 3: Construction of an indoor swamp for a movie set

Fig. 4: Finished Purlear Creek project

REVOLUTION GUNITE

Phone: 336.383.1718

Website: www.revolutiongunite.com

E-mail: info@revolutiongunite.com

NEW ASA MEMBERS

american shotcrete association | asa

CORPORATE MEMBERS

Ironhorse Shoring & Deep Foundation Ltd.
Richmond, BC, Canada
Primary Contact: Frank Fezza
info@ironhorseshoring.com

NMN Shotcrete Construction, Inc.
Sylmar, CA
www.nmnconstruction.com
Primary Contact: Ron Federico
ron.federico@nmnconstruction.com

Pilbaj Concretos S.A. De C.V.
San Luis Potosí, Mexico
Primary Contact: Esteban Vazquez Martinez
estebanwfk@hotmail.com

Platinum Specialty Services
Sewell, NJ
http://platinumss.com
Primary Contact: Robert Gentile
bob.gentile@platinumss.com

R & W Concrete Construction, Inc.
Lansdale, PA
http://rwconcreteinc.com
Primary Contact: Bruce Wilson
bruce@rwconcreteinc.com

Traylor Bros., Inc.
Evansville, IN
www.traylor.com
Primary Contact: Matthew Burdick
mburdick@traylor.com

SUSTAINING CORPORATE ASSOCIATES

Jackson Rand
King Shotcrete Solutions, Oakville, ON, Canada

CORPORATE ADDITIONAL INDIVIDUALS

Dennis Jimenez
AVAR Construction, Inc., Valley Springs, CA

INDIVIDUALS

Mark Bradford
Spohn Ranch Skateparks, City of Industry, CA

Jeffrey Giza
Whitman, Requardt & Associates, Inc., Baltimore, MD

James Ragland
Ragland, Aderman & Associates, Baton Rouge, LA

Seven Slovenia
Seven Refractories D.o.o., Divaca, Slovenia

STUDENTS

Jacob Wilson
Colorado State University, Harleysville, PA

INTERESTED IN BECOMING A MEMBER OF ASA?

Read about the benefits of being a member of ASA and find a Membership Application at **www.shotcrete.org/membership**.

NEWLY FOUNDED WATERSHAPE UNIVERSITY

Watershape University was established to provide high-quality live instruction of business, design, engineering, and construction programs to students of all levels in the pool, spa, aquatics, and outdoor living sectors. It began as a partnership between **David J. Peterson** and ASA member **William T. Drakeley** to train and cross-train the employees of their respective companies. Peterson and Drakeley bring decades of technical and business experience to Watershape University, including their previous roles as Director and Deputy Director of GENESIS® Education and their continuing active involvement with the American Shotcrete Association. For years, they have collaborated on construction projects and provided expert testimony in construction defect cases. They have taught classes on several aspects of business, design, engineering, and construction in the pool, spa, aquatics, and outdoor living industries.

"Our goal is to elevate our industry through high-quality, consistent training and instruction from qualified industry professionals. We believe we can better serve the watershaping industry by connecting with builders and their subcontractors," said Drakeley.

Watershape University has both an East Coast and a West Coast office to maximize its ability to provide training and support throughout North America. Watershape University will offer programs beginning this winter. A course schedule and more details will be released in the coming months.

For more information, call 858.720.1001 or visit **www.watershape.org**.

NEW SHOTCRETE, TUNNELING, AND MINING BUSINESS UNIT ESTABLISHED TO SERVICE NORTH AMERICAN MARKET

King – a Sika Company announced it has established the Shotcrete, Tunneling & Mining (STM) business unit. This business unit was created to target the North American mining and tunneling industry and to further build on the success that King Packaged Materials Company, Construction Products Group has built in the North American shotcrete markets.

Rand

This unit will be led by ASA member **Scott Rand**, who was appointed as Vice President, North America, Shotcrete, Tunneling & Mining. Rand has over 20 years of experience representing the KING brand and is well-recognized in the construction, mining, and shotcrete industries. He will lead an expanded sales team consisting of existing King CP and Sika North America team members.

Shotcrete, Tunneling & Mining will focus on complete shotcrete solutions, including materials and equipment, and will service the growing Canadian and U.S. mining, tunneling, refractory, concrete construction, and concrete rehabilitation markets.

For more information, call 800.461.0566 or visit **www.kpmindustries.com**.

ACI FOUNDATION PARTNERS TO LAUNCH EMBODIED CARBON IN CONSTRUCTION CALCULATOR (EC3) TOOL

The ACI Foundation has partnered with the Carbon Leadership Forum on the launch of the public beta of the Embodied Carbon in Construction Calculator (EC3) tool. The EC3 tool is a free, open-access tool for architects, engineers, owners, construction companies, building material suppliers, and policy-makers to compare and reduce embodied carbon emissions from construction materials, and was launched at Greenbuild on November 19, 2019.

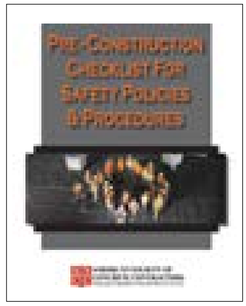
With the launch of the EC3 tool, the building industry has a powerful new tool for supply-chain-specific analysis of embodied carbon data, using the first searchable and sortable database of all United States and Canadian Environmental Product Declarations for concrete, steel, wood, glass, aluminum, insulation, gypsum, carpet, and ceiling tiles. In addition, the EC3 tool is revolutionizing the EPD process. It is the first tool to create a digital EPD form and to translate all EPDs into that form for viewing and analyzing the data. "The American Concrete Institute, ACI Foundation, and the greater concrete community have been developing industry-leading knowledge on the use of concrete in innovative and sustainable development," stated Ann M. Masek, Executive Director, ACI Foundation. "With the generous support of our members and donors, we are pleased to invest in and join the collective in bringing the EC3 tool into practice."

For more information, call 248.848.3737 or visit **www.acifoundation.org**.

PRE-CONSTRUCTION CHECKLIST FOR SAFETY POLICIES & PROCEDURES

The Safety & Risk Management Council (SRMC), a specialty council of the American Society of Concrete Contractors (ASCC), has published a Pre-Construction Checklist for Safety Policies & Procedures. The purpose of the document is to stimulate discussion of job-specific safety protocol and procedures, with all pertinent parties prior to project startup.

The document covers general information such as contact data for significant persons, safety goals and planning, reporting, discipline, and quality of life. It also covers more specific criteria including silica, crane activities, heat, and an evacuation plan.



"Making sure all parties understand and are on board with safety before mobilization is a key factor in maintaining a safe job place," says Joe Whiteman, Director of Safety Services, ASCC. "It's in everyone's best interest to understand what's expected prior to starting work."

ASCC also has checklists for the Pre-Construction Conference, for Pumping Concrete, and for Ordering & Scheduling Ready-Mixed Concrete.

For more information, call 866.788.2722 or visit **www.ascconline.org**.

ACPA Releases Safety Bulletin for Double-Ended Hoses

The American Concrete Pumping Association (ACPA) released a new safety bulletin, *Safe Practices for the Intended Use of Concrete Delivery and End Hoses*. The bulletin addresses the proper methods for using concrete delivery hoses with two ends. Concrete delivery hoses with two ends have different purposes from concrete delivery hoses with one end.

"It's important for concrete contractors and concrete pumpers to understand when and where to use each type, as double-ended concrete delivery hoses increase the potential for serious personal injury when used as an end hose," says ACPA Executive Director Christi Collins. "The ACPA's new safety bulletin responds to a need in the industry for education about the hazards of using double-ended concrete delivery hoses."

Continually updating safety resources is part of ACPA's mission to foster and promote a positive safety culture within the concrete pumping industry. The new safety bulletin complements the association's extensive safety library and is available for free download at **www.concretepumpers.com/sites/concretepumpers.com/files/attachments/sb_endhoses.pdf**.

For more information, call 614.431.5618 or visit **www.concretepumpers.com**.

New Partnership for GeoSLAM and Normet

GeoSLAM announced a new partnership with the underground equipment manufacturer Normet. The companies have joined efforts to develop technology and solutions for mining and tunneling customers to enhance safety, efficiency, and quality of sprayed concrete solutions.

Process Monitor Live, which uses advanced LiDAR technology, provides real-time guidance on the thickness of sprayed concrete being applied to the walls and face of a tunnel during ground support operations. Process Monitor Live is now embedded and available through Normet's SmartScan solution.

The partnership between GeoSLAM and Normet means user-friendly, easy-to-operate technology that is already successful in creating productive, safe underground environments is available to more organizations.

For more information, call 801.596.4700 or visit **www.normet.com**.

SHOTCRETE CALENDAR

FEBRUARY 3, 2020	**ASA Annual Membership Meeting** Las Vegas Convention Center | Las Vegas, NV **www.shotcrete.org/WOC**
FEBRUARY 3, 2020	**ASA 90-Minute Shotcrete Seminar at World of Concrete** Shotcrete Technology for Diverse and Cost-Saving Projects Las Vegas Convention Center | Las Vegas, NV **www.shotcrete.org/WOC**
FEBRUARY 4, 2020	**ASA Shotcrete Nozzleman Education at World of Concrete** Las Vegas Convention Center | Las Vegas, NV **www.shotcrete.org/WOC**
FEBRUARY 4, 2020	**ASA Outstanding Shotcrete Project Awards Banquet** Vdara Hotel & Spa | Vinoly Ballroom | Las Vegas, NV **www.shotcrete.org/WOC**
FEBRUARY 4-7, 2020	**World of Concrete 2020** Las Vegas Convention Center | Las Vegas, NV **www.worldofconcrete.com**
FEBRUARY 5, 2020	**ASA Shotcrete Contractor Education at World of Concrete** Las Vegas Convention Center | Las Vegas, NV **www.shotcrete.org/WOC**
FEBRUARY 23-26, 2020	**2020 SME Annual Conference & Expo** Phoenix Convention Center | Phoenix, AZ **www.smeannualconference.com**
MARCH 3-4, 2020	**New York Build 2020** Javits Center | New York, NY **www.newyorkbuildexpo.com/asa**
MARCH 10-14, 2020	**CONEXPO – CON/AGG 2020** Las Vegas Convention Center | Las Vegas, NV **www.conexpoconagg.com**
MARCH 23-25, 2020	**2020 ICRI Spring Convention** JW Marriott Parq Vancouver | Vancouver, BC, Canada **www.icri.org**
MARCH 28, 2020	**ASA Spring 2020 Committee Meetings** Hyatt Regency O'Hare | Rosemont/Chicago, IL **www.shotcrete.org/calendar**
MARCH 29 – APRIL 2, 2020	**The ACI Concrete Convention – Spring 2020** Theme: "Concrete in the Windy City" Hyatt Regency O'Hare | Rosemont/Chicago, IL **www.aciconvention.org**
JUNE 7-10, 2020	**North American Tunneling Conference (NAT) 2020** Nashville, TN **www.natconference.com**

JUNE 28 – JULY 1, 2020	**ASTM International Committee C09, Concrete and Concrete Aggregates** Boston Marriott Copley Place | Boston, MA **www.astm.org**
SEPTEMBER 28-30, 2020	**MINExpo International** Las Vegas, NV **www.minexpo.com**
OCTOBER 5-7, 2020	**2020 ICRI Fall Convention** Minneapolis Marriott City Center | Minneapolis, MN **www.icri.org**
OCTOBER 25-29, 2020	**The ACI Concrete Convention – Fall 2020** Theme: “Carolina Style Concrete” Raleigh Convention Center & Raleigh Marriott | Raleigh, NC **www.aciconvention.org**
MORE INFORMATION	To see a full list with active links to each event, visit **www.shotcrete.org/calendar**.

ASA FALL 2019 COMMITTEE MEETINGS

Most of the ASA committees met on October 19, 2019, at the Duke Energy Convention Center, Cincinnati, OH. These open ASA meetings take place bi-annually and contribute essential work to the Association. Thank you to all who attended the recent meetings, and we encourage more members to become involved. Those interested can contact ASA by e-mailing info@shotcrete.org for more information.

The Pool and Recreational Shotcrete Committee's Position Statement #7 on Curing was approved at these meetings and can be found in this issue on page 39. Each committee is making progress on their action items with a few new initiatives to be introduced next year.

Notable Committee leadership changes included: Tait Pirkle, Eastco Shotcrete LLC, stepped down as Marketing Committee Chair, and was succeeded by Cathy Burkert, American Concrete Restorations Inc., as Chair, and Ashley Cruz, Cruz Concrete & Guniting Repair Inc., as Secretary; Jason Myers, Dees-Hennessey Inc., assumed Chair of the Membership Committee with Dennis Bittner appointed as Secretary; and Frank Townsend, Superior Gunite, succeeded Andrea Scott, Hydro-Arch, as Chair of the Safety Committee, with Derek Pay, Oceanside Construction, appointed as Secretary. Pool and Recreational Shotcrete Committee Chair Mason Guarino convened with appointed Vice Chair Ryan Oakes and Secretary Mike Reeves taking the lead at these meetings in his absence. ASA sincerely thanks Tait Pirkle and Andrea Scott for their leadership on their respective Committees. ASA is grateful for the time, energy, and passion our active Committee members have shown in moving forward the work of the Association!

SHOTCRETE INSPECTOR CERTIFICATION PROGRAM

ASA's Shotcrete Inspector Education was introduced last year and is now joined by the recently launched, ACI Shotcrete Inspector Certification. The first public session where Education, Inspector reference materials, and the Certification exam were available took place at The ACI Concrete Convention and Exposition in Cincinnati, OH, on October 23, 2019. The Education was facilitated by ASA Education Committee Chair Oscar Duckworth and ASA Executive Director Charles Hanskat, with a 90-minute exam following the education session. The visual cues for quality shotcrete discussed in the course would be beneficial to help contractors work with inspectors who are less familiar with quality shotcrete placement. Refer to the article on page 48 for more details and visit **www.shotcrete.org/events**.

More details on the ACI Shotcrete Inspector Certification program can be found at **www.concrete.org/certification/certificationprograms.aspx?m=details&pgm=Shotcrete%20Inspection&cert=Shotcrete%20Inspector**. In addition, see page 26 to read the article discussing the ACI Shotcrete Inspector Certification program.

ASA AT WORLD OF CONCRETE 2020

World of Concrete (WOC) 2019 will be held February 3-7, 2020, at the Las Vegas Convention Center, Las Vegas, NV. A longtime co-sponsor of this industry event, ASA will be exhibiting at South Hall #S11038 and hosting several events and seminars. Register now using ASA's Source Code: A17 at **www.compusystems.com/servlet/ar?evt_uid=395&PromoCode=A17**. Join ASA for its annual Membership Meeting to hear updates on Association activities and new appointments on February 3 at 2:00 p.m.

Shotcrete Technology for Diverse & Cost-Saving Projects

WOC Registration code: MO115

This ASA 90-minute shotcrete seminar will examine the cost savings that shotcrete provides to general contractors and how those savings are also of value to the owner. Speakers Frank Townsend and Marcus von der Hofen will present challenges associated with shotcrete, including weather conditions and creating the proper mixture design formulation for a successful result. Additionally, an exploration of the proper placement techniques for reinforced concrete sections that require multiple layers of concrete will be reviewed. Finally, attendees will see current shotcrete projects, both structural and architectural, while defining the future potential of the industry.

ASA Shotcrete Nozzlemen Education Class

WOC Registration code: ASATU

The ASA Shotcrete Nozzlemen Education Class is a requirement for all nozzlemen wishing to pursue certification as an ACI Shotcrete Nozzleman through ASA. This 7-hour program provides a great overview of the shotcrete process for owners, contractors, and project managers. This registration includes the required CP60 workbook (available in English or Spanish) and a complimentary 1-year ASA Nozzleman membership. Registering for this class also requires registration for a WOC Exhibit-Only Pass, available for $25 using ASA's source code: A17. Please note this class alone will not result in certification.

ACI Wet-Mix Certification

If you have 500 hours of shooting experience, you may pursue certification, while 25 hours of shooting experience will allow you to pursue a nozzleman-in-training designation. Both a written exam and performance exam(s) are required. ASA is providing an opportunity for those wanting to complete their ACI Wet-Mix Certification or shoot their performance panels for re-certification. To secure a spot send in your full payment and work experience forms for this Las Vegas certification session (Henderson, NV) as soon as possible, but no later than Thursday, January 17, 2020. Contact Andrea Scott directly at 702.280.9332. Those certifying for the first time would also be required to attend the ASA Shotcrete Nozzleman Education Class on February 4 noted above.

ASA Shotcrete Contractor Education

WOC Registration code: ASAWE (course only with reference material);

WOC Registration code: ASAWEX (course, reference material, and exam)

With the strong growth of shotcrete construction, the concrete construction industry needs shotcrete contractors who are knowledgeable about the shotcrete business. This seminar is intended for the existing shotcrete contractor pursuing ASA Shotcrete Contractor Qualification. However, this seminar will be beneficial to all concrete contractors interested in learning more about quality shotcrete placement of structural concrete regardless of interest to pursue certification. Although a concrete contractor may be experienced in form-and-pour concrete construction, shotcrete has fundamentally different equipment, material selection, crew responsibilities, application techniques, testing, curing, and protection that needs to be considered for producing high-quality and durable shotcrete. This course provides "best practices" for the shotcrete contractor looking to grow and increase productivity and quality in shotcrete applications.

This seminar will provide a thorough knowledge of shotcrete placement for concrete construction, including logistics (site and project), environmental requirements, safety, crew requirements, shotcrete equipment, concrete mixture design, QA/QC, surface preparation, formwork, reinforcements, embedments, placement, finishing, curing, and protection. Referenced ACI documents provided with the seminar includes ACI 506.2-13, "Specification for Shotcrete," and ACI 506R-16, "Guide to Shotcrete."

Those qualifying individuals pursuing ASA Shotcrete Contractor Qualification for their company who attend the 7-hour course will need to take a 90-minute written exam at the end of the seminar. For more information, visit **www.shotcrete.org/pages/education-certification/cq-program.htm**.

ASA Outstanding Project Awards Banquet

Join ASA and industry leaders to celebrate the outstanding work demonstrated in the shotcrete industry at ASA's Outstanding Shotcrete Project Awards Banquet on February 4, 2019, at the Vdara Hotel & Spa, Las Vegas, NV. This capstone event will reveal the 2019 Outstanding Shotcrete Project Awards winners. Register for this event at **https://shotcreteregistration.secure-platform.com:443/a/solicitations/1012/home**.

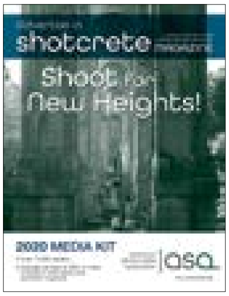
SAVE THE DATE! 2021 SHOTCRETE CONVENTION & TECHNOLOGY CONFERENCE

February 21-23, 2021 Sonesta Resorts | Hilton Head, SC

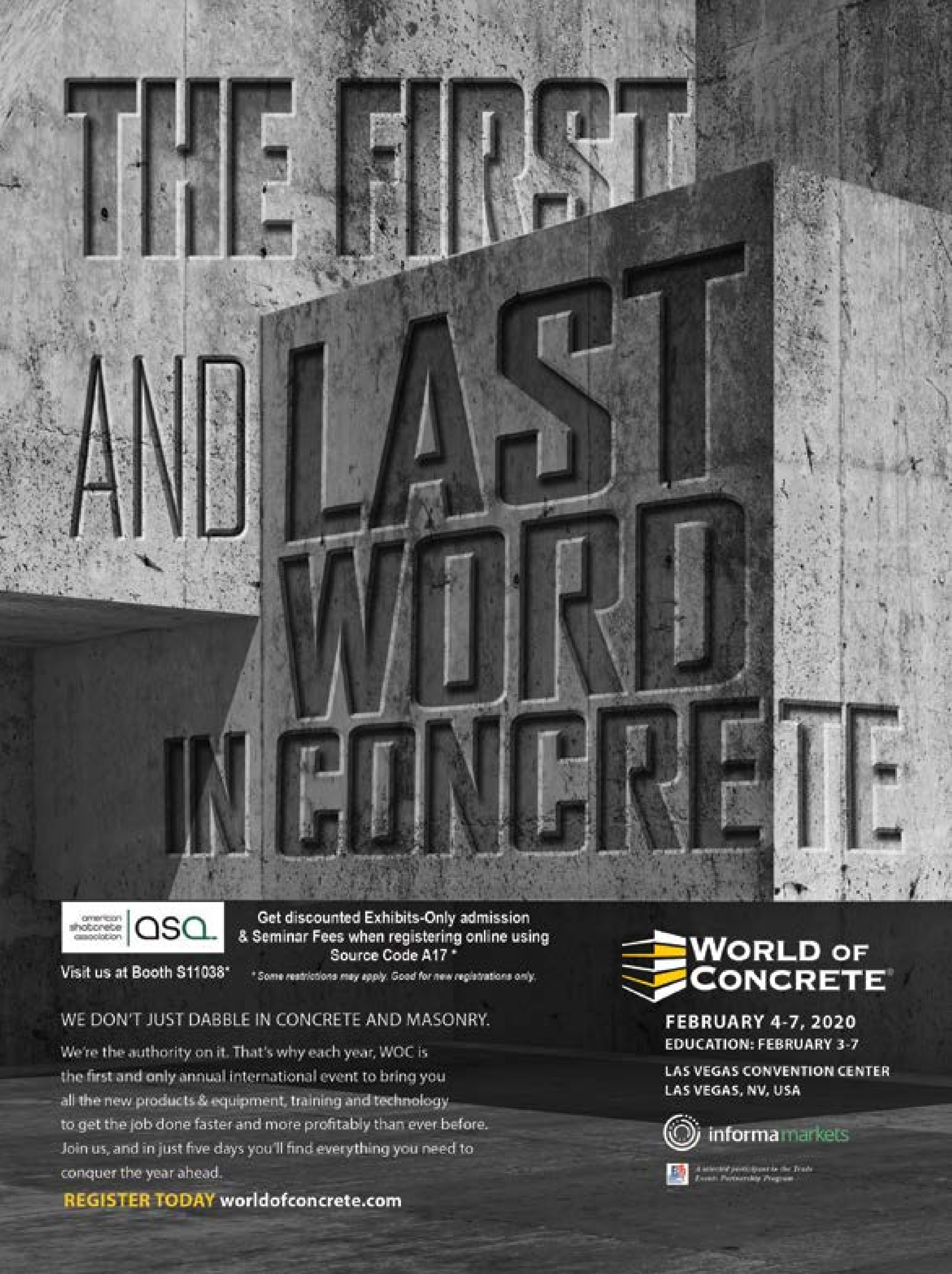
SHOTCRETE CONVENTION & TECHNOLOGY CONFERENCE

Plan to attend this unique event designed for the shotcrete community. Join other leaders in this field to learn, network, and share knowledge over the technical sessions, committee meetings, exhibits, social activities, and meals! The 2020 Outstanding Shotcrete Project Award winners will be celebrated at this event. Call for presentations will be coming out soon.

2020 SHOTCRETE MEDIA KIT



Shotcrete magazine is the only international magazine focused exclusively on the growing shotcrete industry. Marketing in *Shotcrete* magazine is an investment—not only in your company's growth, but also in supporting the expansion of the shotcrete market. The 2020 themes include Winter 2020, Awards; Spring 2020, Innovations in Shotcrete; Summer 2020, Safety; and Fall 2020, Equipment. The 2020 media kit can be found at **www.shotcrete.org/media/pdf/ASAMediaKit.pdf**. For more information, rates, and deadlines, contact Lacey Stachel, ASA Editorial and Marketing Manager, at lacey.stachel@shotcrete.org or 248.848.3736.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BLASTCRETE EQUIPMENT RS180 MIXER-PUMP

Blastcrete Equipment LLC introduced the RS180 Mixer-Pump with variable speeds from 0 to 18 yd³/h and long-distance and high-volume pumping capabilities. The RS180 is a user-friendly, economical option for gypsum flooring underlayment, grouting, cellular concrete, and some wet-mix shotcrete applications. It provides a smooth material delivery for specialty applications, ease-of-use for operation and maintenance, and durability for optimum efficiency in a variety of applications.

To eliminate material surges and provide higher pumping volumes, the RS180 incorporates an adjustable 2L8 rotor-stator pump. The adjustable rotor-stator, or progressive cavity, design allows contractors to tailor material flow to the job at hand. By tightening the unit, operators can increase line pressure for longer vertical or horizontal pumping distances. For shorter distances, the unit can be loosened.

The RS180 features a 12 ft³ (0.3 m³) hydraulic spiral mixer, driven with a planetary gearbox, providing variable speed

from 0 to 60 rpm for application- and site-specific adjustments. Mixing a full load in less than 2 minutes, it minimizes downtime and provides a continuous flow of material. A 15 ft³ (0.4 m³) receiving hopper, easily charged with 1000 lb (450 kg) bulk bags or 11.6 ft³ skid steer bucket, further increases jobsite efficiency.

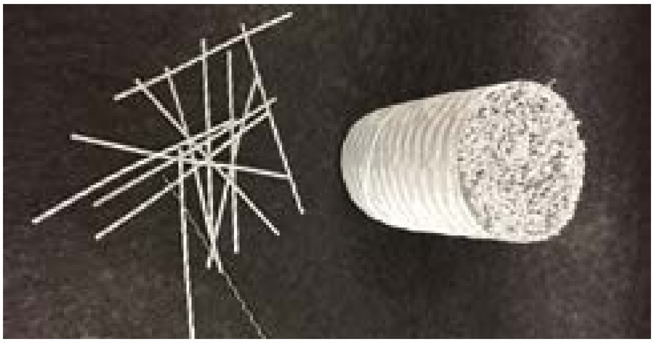
The robust mixer's cleaning and wear parts are easily accessible for ease of maintenance. Additionally, the mixer offers hassle-free removal with complete detachment from the unit after removing only four bolts.

For more information, call 800.235.4867 or visit **www.blastcrete.com**.

SIKAFIBER ENDURO PRIME OBTAINS ICC EVALUATION SERVICES REPORT FOR AC383

Sika announced that SikaFiber® Enduro® Prime obtained an ICC Evaluation Services (ES) Report for AC383. The International Code Council (ICC) develops model codes and standards used in the design, building, and compliance process to construct safe, sustainable, affordable, and resilient structures, such as the International Building Code and the International Residential Code. The ICC Technical staff develops Acceptance Criteria (AC) for new and innovative products which are approved by the Evaluation Committee during open public hearings. The Evaluation Committee is made up entirely of code officials. The AC for Polyolefin Chopped Strands (Macro Synthetic Fiber) for use in concrete is AC383.

The ICC-ES Reports verify that new and innovative building products comply with code requirements and recommendations for use. SikaFiber Enduro Prime had to go through a battery of stringent third-party testing to achieve the ICC ES Report 4282. The testing for the evaluation report included



the following; Freeze Thaw (ASTM C666), Plastic Shrinkage Cracking Resistance (ASTM C1579), Ring Shrinkage (ASTM C1581), and the Flexural Performance of Fiber Reinforced Concrete (ASTM C1609). The macro fibers excelled at all testing at a minimum dosage of 3 lb/yd^3 (1.8 kg/m^3).

Copies of all "Fibers for reinforcing concrete" ES Reports can be found on the ICC Reports Directory at **https://icc-es.org/evaluation-report-program/reports-directory**.

For more information about Sika, call 201.933.8800 or visit **usa.sika.com**.

KRYTON INTERNATIONAL ADDS WIRELESS REAL-TIME CONCRETE MONITORING TO ITS SMART CONCRETE PRODUCT OFFERING

SMART CONCRETE®

Kryton International Inc. acquired 30% interest in Sensohive Technologies ApS of Odense, Denmark. The acquisition makes Kryton Sensohive's largest shareholder. Kryton will also be the exclusive North American distributor of Sensohive's Maturix™ technology, which uses advanced sensors and software, enabling contractors and engineers to wirelessly monitor the concrete hardening process in real time from an internet-connected device.

"The ability to monitor concrete strength in real time from remote locations helps expedite faster construction schedules, optimizing efficiencies, reducing costs, and improving safety," said Kryton's President and CEO, Kari Yuers.

Real-time monitoring of structures is an evolving field in the construction through the rapidly expanding Internet of Things (IoT)—the interconnected digital network allowing everyday objects to be embedded with electronics collecting and sharing data. Maturix technology runs on the Sigfox 0G network, the world's largest IoT network covering 1 billion people in 65 countries. Sigfox's long-range and low-power-demand network allows Sensohive's sensor batteries to last for up to 10 years.

Maturix uses thermocouples and reusable temperature sensors providing real-time connectivity and remote monitoring of concrete maturity and strength. Data is automatically collected every 10 minutes and transmitted wirelessly to the cloud with information available in various report formats.

For more information about Kryton International Inc., call 800.267.8280 or visit **www.kryton.com**. For more information about Sensohive ApS, visit **www.sensohive.com**.

CEMEN TECH CONNECT

Cemen Tech now offers real-time support services. Cemen Tech CONNECT features real-time video field support at the push of a button. Users are immediately connected to a field support expert via live video calling, who can then assist with troubleshooting, part identification, and field evaluations. Live multi-party video calling provides users the ability to share content such as pictures, video, and parts manuals across multiple screens. The on-screen annotation feature allows users to draw, point, or circle right on the screen for simplified communication. Field support experts can then provide information for any necessary parts or problem resolution. This free application is available for Apple and Android devices.

For more information, call 800.247.2464 or visit **https://cementech.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 **http://shotcrete.org/pages/products-services/technical-questions.htm**.

Question: *I have a 24 in. (610 mm) thick shotcrete wall that needs to be scanned for voids. The project has been struggling to locate a local expert who has the capability to scan this thick of a wall. In addition, this new 24 in. thick shotcrete wall was dowelled and made an "as-one-unit" together with an existing 24 in. form-and-pour wall. Any thoughts and ideas would be greatly appreciated.*

Answer: Shotcrete is a placement method for concrete. Thus, all nondestructive testing (NDT) applicable to concrete walls would be usable on your wall. However, it is difficult to get good results with a scanning system for heavily reinforced concrete walls of your thickness. Impact echo and impulse response are two one-sided techniques that can provide good results for a portion of the 24 in. thickness, although they would likely not be able to scan the entire depth. Ultrasonic pulse velocity is a potential if you can access both sides of the wall. For one-sided investigation at greater depth, you may be able to use a MIRA system. It is a sophisticated tomographic system that says it can test from 50 to 800 mm (32 in.) thickness. There are national consulting firms that provide these investigation systems. Each requires a highly trained, experienced operator—so be sure to verify the firm can document successful experience using the method.

Question: *We are working on a repair/renovation project in Boston, MA. A long, concealed wall next to an adjacent property is now visible, as the adjacent property is being renovated. We have been told that our wall must now have a 2-hour fire rating. Our wall is comprised of concrete masonry units (CMUs) and exposed structural steel members. Applying shotcrete to the CMUs and steel is a good solution for several reasons. Can you provide or point me to a shotcrete specification that will have a 2-hour fire rating on CMUs and structural steel?*

Answer: Shotcrete is a placement method for concrete. Thus, the fire resistance for shotcrete placement is the same as concrete. The primary reference for fire resistance of concrete is ACI 216.1-14(19), "Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies."

Question: *Is there any article or reference referring to the procedure of maturity of the concrete applied to the shotcrete? Basically, explaining how to generate the validation curves?*

Answer: Shotcrete is a placement method for concrete. Thus, generating the maturity curves are based on the concrete mixtures. There are several online resources about the maturity method. The Minnesota DOT provides a PDF resource that discusses production of the curves and is available at **www.dot.state.mn.us/materials/concretedocs/MaturityMethodProcedure.pdf**.

Question: *I am working with a private club in Connecticut and we are are trying to determine what the life expectancy is of a concrete commercial pool shell. There is no evidence of failure or cracking and the pool surface is painted, not plaster. We think it is reinforced shotcrete. Are there any tests or rules we should take into consideration?*

Answer: Shotcrete is a placement method for concrete. Thus, evaluating your pool shell life expectancy will be the same as any concrete structure exposed to water. You may find the technical document ACI 201.1R-08, "Guide for Conducting a Visual Inspection of Concrete in Service," helpful in evaluating your pool shell. Generally, shotcreted concrete that uses quality materials, proper equipment, and placement techniques will serve for at least 50 to 60 years. ACI 350-06, "Code Requirements for Environmental Engineering Concrete Structures," states: "When all relevant loading conditions are considered, the design should provide adequate safety and serviceability, with a life expectancy of 50 to 60 years for the structural concrete." This ACI 350 Code is for liquid-containing concrete structures such as tanks for water and wastewater treatment but the original pool design may or may not meet the Code requirements.

Question: *I am helping to design radiation shielding for a cyclotron and we do not have much space. The machine produces both neutrons that must be shielded for as well as gamma rays. I have been told that we could get a density of 3.2 g/cc, which helps for gamma rays, but I need to find out more about the water content of the finished product for the neutron shielding part so I can scale between regular 2.4 g/cc concrete and the high-density shotcrete product. Do you have knowledge of this?*

Answer: Shotcrete is a placement method for concrete. We have shot a wide variety of concrete mixtures from lightweight to heavyweight to the use of alternative cements. Reviewing ACI 304.3R-96, "Heavyweight Concrete: Measuring, Mixing, Transporting, and Placing," the key to producing heavyweight concrete is the aggregates used.

The document also mentions that more cement paste is needed in heavyweight concrete and that helps to increase pumpability, which is important to use with shotcrete placement. Shotcrete will allow you to minimize or eliminate formwork, so it may have benefits of reducing cost and time for construction. Wet-mix shotcrete generally has a low water-cementitious materials ratio (*w/cm*) of 0.38 to 0.45. Dry-mix shotcrete tends to be even lower with a 0.35 to 0.40 *w/cm*. Shotcrete materials achieve this using high-range water-reducing admixtures. As concrete hydrates and gains strength, the available free water in the concrete is consumed, and so may be less of a problem for shielding. Reviewing the 304.3R document, it appears reaching the 3.2 g/cc density is fairly easy, and even higher densities may be achievable. You may want to review the ACI 304.3R document, as it provides a good background of heavyweight concrete mixture design and use.

Question: *We have a project where the results of a shotcrete material test panel were deemed to not meet the required compressive strength requirements of ACI 506R-13(18) under Section 1.7—Acceptance of Work. That section states:*

> *"1.7.6.1 Compressive strength—Consider the compressive strength adequate if the average of the three cores from a test panel or from in-place shotcrete exceeds 85 percent of the specified compressive strength and no single core is less than 75 percent of the specified compressive strength."*

Our specified 28-day compressive strength was 5500 psi (38 MPa). The average of three cores met the 85% requirement but we had one core that fell just 100 psi (0.7 MPa) short of the 75% requirement. A fourth core was taken and had a compressive strength well above the specified 5500 psi. Is there a tolerance on compressive core breaks? Is it acceptable to use the additional core taken from the same panel to evaluate the strength? Also, this is a non-structural shotcrete overlay that is provided for additional cover over the existing sections. Is 5500 psi needed to provide good-quality, durable shotcrete? We were shooting the specified 3:1 mixture so it had a lot of cement in the mixture.

Answer: Erroneous results from coring of shotcrete material test panels is a common problem in shotcrete testing. ASTM C1140/C1140M and ASTM C1604/C1604M are the testing standards that cover shotcrete test panels. Panels are heavy, well over 100 lb (45 kg), and can be mishandled in the field and around the testing lab. Field-induced problems may include:

- Moving the panel too early before the concrete has sufficient strength to withstand dropping or transport;
- Not providing tight wrapping of the panel soon after shooting, allowing excessive surface evaporation of water; and
- Not protecting the panel from excessive temperature gain at the surface (exposure to direct sunlight) that can cause differential temperature stresses in the panel.

Testing of the panels can also be difficult to do properly. Lab-induced problems may include:

- Not taking proper care of the panel in moving it to or around the lab (again, the panels are heavy and cumbersome to move);
- Not keeping the panels in a moist condition;
- Coring too close to the edge of the panel (should be depth of panel plus 1 in. [25 mm]);
- Coring irregularities that introduce corrugations or striations in the surface;
- Not coring the individual samples immediately before testing (2 hours or less) or following the moisture conditioning of ASTM C1604/C1604M when specified; and
- Not capping or sawing the ends if the end surfaces don't meet the perpendicularity and planeness of ASTM C39/C39M.

Thus, you can see there are many factors that can produce less-than-accurate results in the coring for shotcrete material compressive strength testing. With the many factors affecting the cores, it is instructive to consider the precision statement in ASTM C1604:

> "8.10.2 The single-operator coefficient of variation on concrete cores has been found to be 3.2% for a range of compressive strength between 4500 psi [32.0 MPa] and 7000 psi [48.3 MPa]. Therefore, results of two properly conducted tests of single cores by the same operator on the same sample of material should not differ from each other by more than 9% of their average.
>
> 8.10.3 The multi-laboratory coefficient of variation on cores has been found to be 4.7% for a range of compressive strength between 4500 psi [32.0 MPa] and 7000 psi [48.3 MPa]. Therefore, results of two properly conducted tests on cores sampled from the same hardened concrete (where a single test is defined as the average of two observations (cores), each made on separate adjacent drilled 4-in. [100-mm] diameter cores) and tested by two different laboratories should not differ from each other by more than 13% of their average."

The 100 psi (0.7 MPa) low compressive strength value in this case is less than 2% of the specified 5500 psi 28-day compressive strength. Thus, the expected variation and accuracy of the core test when everything is conducted properly for the single operator at 5500 psi at 9% would be 495 psi (3 MPa). Further, considering an extra core was taken from the same panel, and it far exceeded the required strength would seem to indicate some irregularity in the testing. Thus, considering the expected tolerance of the test, and the apparent variability in the tests, the 100 psi low value could be reasonably considered within the required strength of 75% of 5500 psi.

Also, corrosion protection provided to embedded reinforcement in concrete is provided by the high alkalinity of the cement in the mixture. Lower permeability also provides better resistance to water or chemical penetration. The 3:1 concrete mixture you used has more cement content than required in most dry-mix projects. Thus, your mixture provides an abundance of cement paste in the fresh concrete that will provide a highly alkaline environment and, when properly placed, a low permeability. ASA's Board position is that quality, durable shotcrete must have a 28-day compressive strength of 4000 psi (28 MPa) or greater. In general, shotcrete placement at high velocity provides fully compacted, dense concrete in place. That strength is easily achievable with quality materials, proper equipment, and shotcrete placement by experienced ACI-certified nozzlemen. You may want to reference the *ACI Materials Journal* paper, "Comparative Evaluation of Transport Properties of Shotcrete Compared to Cast-in-Place Concrete," (**www.shotcrete.org/media/Archive/2016Sum_ACIMaterialsJournal-reprint.pdf**) that found shotcrete placement produced concrete in-place with better transport (durability) properties than form-and-pour concrete using the same concrete materials.

Question: *How thick would you recommend a shotcrete application be to make bedrock reservoir waterproof?*

Answer: There are many variables that would need to be considered to answer your question. Water flow, depth of the application, and overall geometry can influence the required thickness. This is a question that should be addressed by an experienced engineer who can ascertain the required structural properties to resist the hydraulic loads for the depth and geometry of your application. You may find consultants who are ASA Corporate Members on our Buyers Guide at **www.shotcrete.org/BuyersGuide**.

Question: *When applying 6 in. (152 mm) of shotcrete on an exterior concrete surface, how long should that cure before coating with an acrylic elastomeric roof coating? What is the moisture content of that thickness after 7 days, or after 14 days?*

Answer: Shotcrete is just a placement method for concrete. Thus, the in-place material will have the same characteristics as concrete. You should consult the coating supplier to establish how long they want the concrete surface cured. They may also specify a certain limit for surface moisture conditions. There are several methods for evaluating the moisture content of the in-place concrete. Here are the ASTM standards that deal with surface moisture:

- ASTM F710, Preparing Concrete Floors to Receive Resilient Flooring; Section 5.2, pH Testing;
- ASTM F1869, Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride;
- ASTM F2170, Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes;
- ASTM F2659, Preliminary Evaluation of Comparative Moisture Condition of Concrete, Gypsum Cement and Other Floor Slabs and Screeds Using a Non-Destructive Electronic Moisture Meter; and
- ASTM F3191, Field Determination of Substrate Water Absorption (Porosity) for Substrates to Receive Resilient Flooring.

In addition, The International Concrete Repair Institute (ICRI) has a certification program, "ICRI Concrete Slab Moisture Testing Technician—Grade 1."

Question: *I place shotcrete and I use the wet-mix method. I have been asked by a contractor to repair a pool that was shot with the dry-mix method. He is having trouble convincing his client that with the proper preparation we can shoot the repair with the wet method. Am I missing anything?*

Answer: Shotcrete is a placement method for concrete. Both wet-mix and dry-mix produce quality in-place concrete when using quality materials and proper equipment and placement techniques. There are no compatibility problems with shooting wet-mix over dry-mix. Basically, it is just shooting shotcrete on top of already placed concrete. For proper bond, the surface of the existing dry-mix must be roughened, cleaned, and brought to a saturated surface-dry moisture condition before shooting the wet-mix lining.

Question: *We are applying shotcrete in a slope (8 in. [200 m]) to make it stable. The shotcrete wall has a length of 330 ft (100 m). Do we need to specify construction and an isolation joint? In case it is required as well as an isolation joint, does the separation between joints need to be 30 ft (9 m)? Where can I find information about joints for shotcrete?*

Answer: Shotcrete is a placement method for concrete. Thus, you should place movement joints (contraction, expansion, isolation) as would be required by your local design codes for concrete. Joint spacing will depend on the amount of reinforcement used in the section to resist temperature and shrinkage volume changes. Construction joint spacing can be determined by the contractor depending on their production rates. Properly prepared construction joints will act as monolithic concrete as long as the joints are properly prepared and proper concrete materials, equipment, and placement techniques are used by the shotcrete contractor. Construction joints should be roughened, cleaned, and then dampened to saturated surface-dry conditions before subsequent shotcrete placement.

The U.S. Bureau of Reclamation has a nice summary document that you may find helpful in your design at **www.usbr.gov/tsc/techreferences/mands/mands-pdfs/JointSpacingForConcreteStructures_09-2016_508.pdf**.

Question: *I have a project where we are designing a shotcrete wall. The contractor plans to mix the shotcrete on site and we need to work with them to come up with a mixture design. Do you have any suggested wet-mix shotcrete designs for on-site mixing applications or could you point me where some may be published?*

Answer: Shotcrete is simply a placement method for concrete. Most wet-mix shotcrete contractors use a 2 in. (50 mm) diameter delivery hose, so maximum coarse aggregate size should be limited to 3/8 in. (10 mm) nominal. Pumpability usually requires a good paste content. Here's a link to an article, "Understanding Wet-Mix Shotcrete: Mix Design, Specifications, and Placement," that should answer many of your questions (**www.shotcrete.org/media/Archive/2003Sum_jolinbeaupre.pdf**). It is rare to have wet-mix concrete mixed on site from bulk aggregate and cementitious materials. Most site-batched wet-mix uses dry prepackaged materials that have metered water addition to provide a specific water-cementitious materials ratio (*w/cm*) for the provided bagged mixture. We also see volumetric mixers used on site that can precisely meter the dry concrete materials and water often with needed water-reducing air-entraining admixtures.

Question: *I'm hoping you'd be willing to answer a couple of questions I have about gunite. I am having a swimming pool installed at my house in Florida. I was away when the gunite was shot a few weeks ago and didn't know at the time that the gunite should be sprayed with water for a few times a day for about a week according to what I have read online. The pool company owner knew I would be away and never mentioned the need for the gunite to be periodically moistened. The owner also made no provision for any of his employees to hose it down or install a sprinkler. When I learned after the fact of the watering requirement and asked him about it, he said it was unnecessary because the gunite was shot at 4000 psi (28 MPa) and not the "industry standard" of 3000 psi (21 MPa). Then he added that with the almost daily rain in Florida at this time of year, all was okay. I'm concerned about the gunite's integrity—its permeability* *and the possibility of shrinkage and cracking. Could you tell me if I have a reason to be concerned, and if so, what do you suggest I should do about it?*

Answer: Gunite is the original tradename for what we now call dry-mix shotcrete. Shotcrete is a placement method for concrete, so recommendations for curing and protection follow general ACI guidelines for exposed concrete. ASA recommends a minimum of 7 days of continuous (not just a few times a day) wet curing to help control shrinkage issues, increase strength, and reduce permeability in young concrete sections. Lack of curing and exposure to windy, hot, or dry conditions will certainly increase the potential for shrinkage and cracking of the concrete. Lack of curing will prevent the concrete from achieving its maximum potential strength.

Shotcrete placement with quality materials and proper application techniques generally exceeds the minimum 4000 psi 28-day compressive strength ASA recommends. The statement that 3000 psi is the "industry standard" is not true, as the ACI 350 Code for concrete liquid-containing requires a minimum 28-day compressive strength of 4000 psi for concrete intended to have low permeability when exposed to water. The required strength depends on the pool design. If you want to confirm the compressive strength of your in-place concrete, cores taken from the pool should be tested for compressive strength by a qualified testing lab. ASTM C1604/C1604M provides guidance on taking cores from existing structures. A minimum 3 in. (76 mm) diameter core is recommended. Before coring, it is recommended to use ground-penetrating radar (GPR) or similar equipment to identify the location of reinforcement in the pool section, and then take cores to avoid cutting through the reinforcement wherever possible. The core holes would then need to be filled with a high-strength, non-shrink cementitious grout. Once you learn the actual strength, you would need to check with the pool design engineer to verify the strength is adequate for the design. If the strengths are not adequate, you should consult with the pool designer or a licensed professional engineer experienced in pool design for potential solutions.

Regarding cracking, the lack of curing will increase the concrete's shrinkage and correspondingly the potential for cracking. You should verify that there are no significant cracks in the pool shell before the plaster or other interior coating is applied. If there are cracks, the pool contractor should repair those before proceeding with the plaster or coating. Although proper curing would certainly decrease the concrete's permeability, generally good-quality shotcrete with proper placement and a strength of 4000 psi will be functionally watertight and not allow any significant amount of water to flow through the uncracked concrete thickness. You will find more detailed information on pool compressive strengths and watertightness of pool shells in our ASA position papers at **www.shotcrete.org/resources**.

Question: *I am not sure if this is the right place to go... 15 months ago I contracted with a company to remove my pavers, pour a concrete pad, and install spraycrete. It was beautiful! The contractor even has photos on his website. Now, I have hairline cracks all over the place and there are more weekly. My contractor is definitely giving me the runaround regarding this. I explained that I would not have paid more than $16,000 if my pool deck would be cracked a year later. Hurricane Irma took out my pool cage and the insurance money was not enough to replace it, so I used the money for my pool deck. Can someone please tell me what to do? Should these hairline cracks be everywhere? What is the lifespan of the material? Help!*

Answer: Spray-crete is NOT shotcrete. Shotcrete is high-velocity placement of concrete in thicker structural sections. It appears Spray-crete is a low-velocity sprayed mortar product generally applied in a very thin layer to provide texture to an existing concrete substrate. Since you mentioned the underlaying concrete pad was cast and then the Spray-crete added the cracking could well be originating in the underlaying concrete. Concrete cracks for a variety of reasons, such as drying shrinkage, thermal volume change (summer/winter cycles), inadequate curing, insufficient reinforcing steel, or settlement of the subgrade. You should locate a local professional engineer experienced in concrete slab evaluation who can evaluate your site, materials used, application techniques, and potential causes of the cracking. You may find the Florida Engineering Society (**www.fleng.org**) and ACEC-FL has a list of firms who offer evaluation services.

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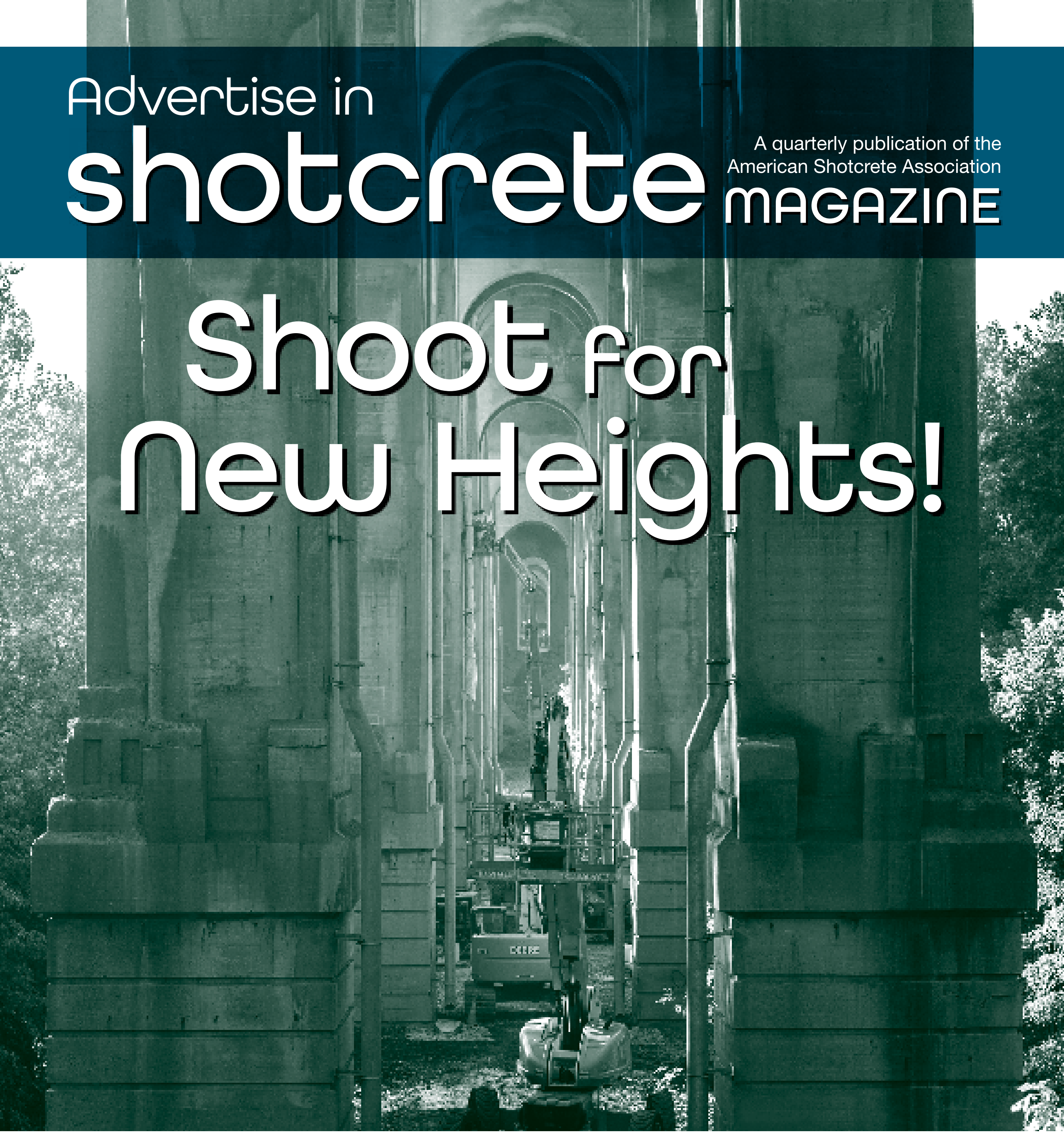

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