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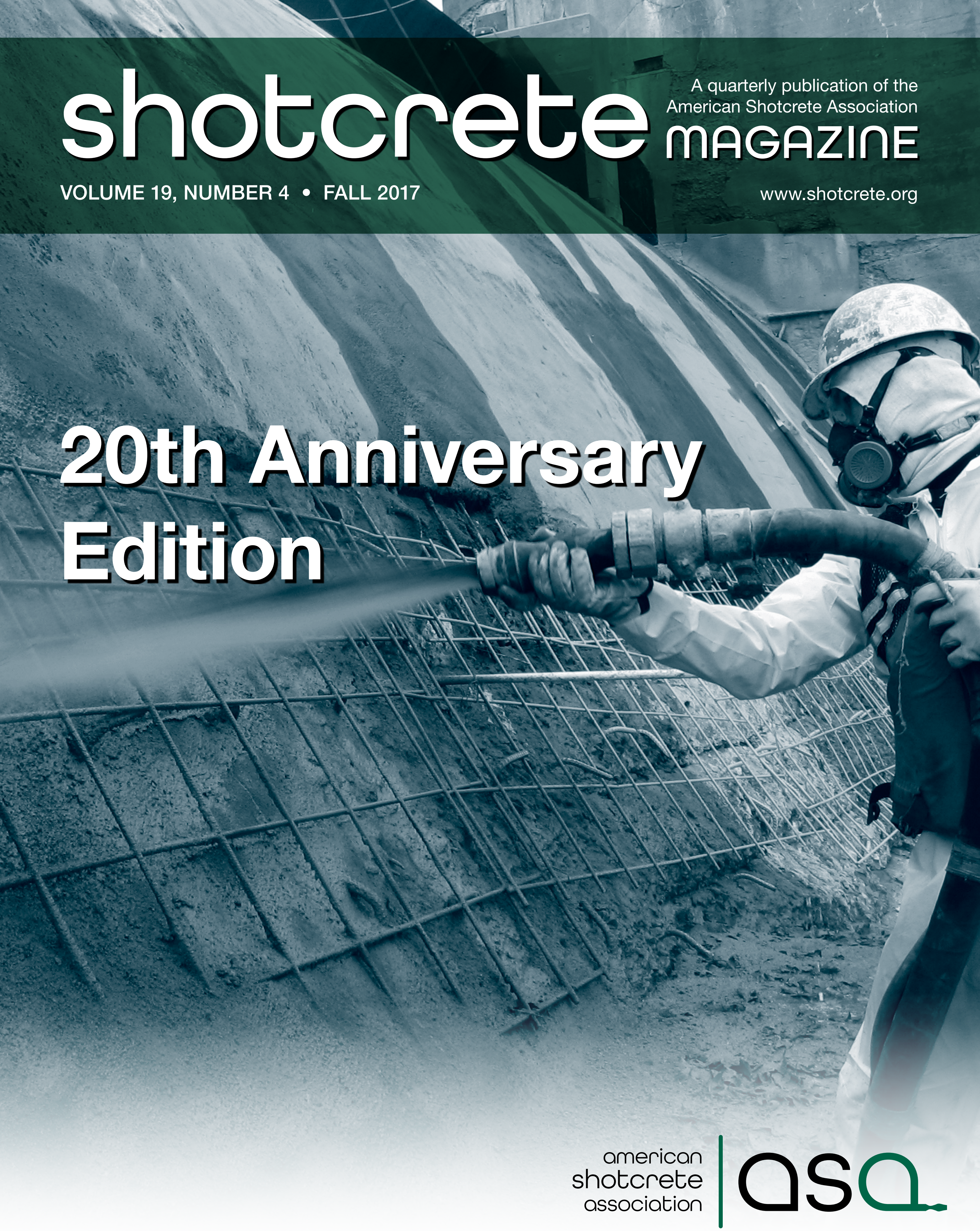

20th Anniversary Edition

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FEATURES

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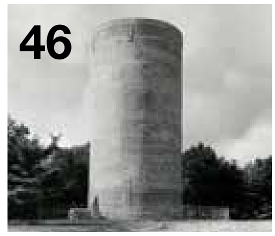
The opinions expressed in *Shotcrete* are those of the authors and do not necessarily represent the position of the editors or the American Shotcrete Association.

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).

FEATURES, cont.



DEPARTMENTS

On the cover: ASA's 20th Anniversary Commemorative issue. See the full Shotcrete Convention & Technology Conference insert on pg 41.

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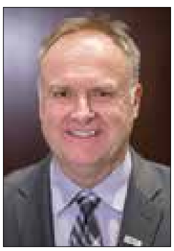
Why Are You Not Seated at Our Table?

By Scott Rand



The past few years have given me a more accurate appreciation for our Association's accomplishments during its first 20 years. I thought having spent a couple of terms on the Board of Directors that I had a reasonable grasp on the effort required to produce those results. However, the opportunity to serve on the Executive Committee, often discussing in detail the numerous particulars behind the scenes, has given me greater insight into the volume of work necessary not only to accomplish those early goals but also the current and next-step goals required. This clarity has resulted in complete admiration for both the people who have served and for those who continue to serve today. Their collective, tireless passion and determination has benefitted our industry greatly.

Currently, our Association could not possibly achieve these objectives without the benefit of our Executive/Technical Director, Charles Hanskat, or our Program Coordinator, Alice McComas. This has become even more evident to me during our monthly meetings. If you are a member of the American Shotcrete Association, you should be proud of the quality of work being continually produced by these two.

Having said that brings me to my main point. If you are involved in the shotcrete industry or make part of your compensation from this business, why on earth are you not sitting at our table?

If you are a shotcrete contractor or a contractor who periodically uses shotcrete as one of your concrete placement methods, accomplishments produced by our Association over the past 20 years have definitely had a positive impact on the industry and your business. The acceptance of shotcrete as either a new construction or repair method has grown tremendously since 1998.

That benefit originated with the development and continued success of this Association. Going back to the inception of the ACI Nozzleman Certification, this program—which began as an ASA initiative to gain credibility and set a quality standard within this industry—has now certified well over a thousand nozzlemen across not only this continent but also in countries as far away as Australia. The success of this initiative not only continues to break records annually but also now incorporates the Nozzleman-In-Training program.

Shotcrete seminars at such venues as World of Concrete, the International Bridge Conference, ConAgg/ConExpo, and the International Pool | Spa | Patio Expo, among others, are great examples of our Association hard at work educating the concrete construction industry. When able, we have held the ASA Shotcrete Nozzleman Education (a prerequisite for shotcrete certification) at these shows and next year, will offer it in both English and Spanish at World of Concrete 2018!

Following this need to educate nozzlemen, ASA has also been actively working to provide credentials for project owners to assess contractors fluent in the type of shotcrete work needed for their projects. Our Contractor Qualification program is anticipated to be unveiled next March in Napa, CA, at our 20th Anniversary Shotcrete Convention.

Our website is without question the best resource in the world, especially because it contains the digital archives of our quarterly magazine. All these past and current benefits have been available to our members at a rate that hasn't increased over the past 20 years.

From a safety perspective, we are well on our way to providing a comprehensive safety presentation that will work in chronological order from mobilizing on site to actual shooting and finishing.

If you are an engineer or owner who specifies sprayed concrete or shotcrete, our *Shotcrete* magazine has offered countless insights on construction techniques and creative applications using this placement method, as well as articles on specifying and inspecting shotcrete. We have offered complimentary on-site presentations for years (companies frequently request this for their lunch-and-learn programs) and have recently completed a version specific to underground construction. We can also offer these AIA CES seminars in a webinar format.

If you are an owner or government authority, our Executive/Technical Director has been working with numerous Departments of Transportation and other agencies over the past couple of years to support your needs. Please don't hesitate to reach out to Charles Hanskat to either present to your group or comment on your specific requirements. Meeting a need for inspectors, we are currently piloting our Shotcrete Inspector Education program and anticipate its availability in early 2018. This is expected to also serve as the primary education of the Shotcrete Inspector Certification Program our members are currently working with the American Concrete Institute in developing.

If you come from an academic angle, our Technical Committee is currently working on tools to help educators put together a program to address potential gaps within either the mining or civil engineering curriculums. We have also fostered learning in post-secondary education through outreach programs including educational seminars, a scholarship program, and a student competition. ASA has also funded research projects uniquely focused to better the shotcrete industry.

Regardless of your needs, ASA is a tremendous resource that is available to assist you in realizing your objectives. As you can see, we at ASA have been hard at work. As I asked earlier, if this is your industry, why are you not seated at our table? Our momentum is changing the industry and as far as I see it, there is only one way for you to have a direct voice. Contact us at your earliest convenience, or better yet, pull back a chair and have a seat at our table.

Save the Date!

Come Celebrate 20 Years of the American Shotcrete Association in Napa, CA!

By Joe Hutter

As our Association prepares to celebrate a significant milestone, the question of how to best recognize 20 years of ASA was a lively discussion point during our spring meeting in Farmington Hills, MI. Much of the discussion focused on changes to our annual Outstanding Shotcrete Project Awards Banquet—some changes were minimal and others quite significant.

A small task group made up of former Board and Officer members, whose involvement in ASA dates back to our association's first year, accepted the responsibility of redesigning the program to make it worthy of celebrating ASA's 20 years in existence. After much research and discussion, the task group unanimously agreed that ASA would combine its 13th annual Shotcrete Project Awards Banquet with its first Shotcrete Convention and Shotcrete Technology Conference in the spring of 2018, March 11-13. Befitting the importance of the event, we recommended an upscale destination—the Silverado Resort and Spa in Napa, CA.

The 3-day Shotcrete Convention will bring together, in one location, our annual Shotcrete Project Awards Banquet, Spring Committee meetings, and the ACI C660 Nozzleman Certification Committee, which has agreed to hold their spring meeting at the ASA event. Also included in the itinerary will be the full-day Shotcrete Technology Conference to give those attending insights into the leading edge of shotcrete technology, both for today and the future.

ASA will also be rolling out its long-awaited Contractor Qualification Program at the Napa event, which will include the opportunity for contractors to send one or more company representatives to the full-day ASA Contractor Qualification Seminar. This seminar will cover a range of topics relevant to shotcrete contractors and its completion will be a mandatory requirement for the ASA Contractor Qualification Program.

There will also be plenty of opportunity for attendees and their guests to enjoy the many unique experiences offered by Napa Valley and the Silverado Resort and Spa. In addition to the many resort amenities and activities offered at the 1200-acre facility, attendees and their guests will have the opportunity to participate in several featured events, including the first ASA Golf Outing at Silverado's

ASA MARKETING COMMITTEE

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Patrick Bridger | King Shotcrete Solutions
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Raymond Schallom | RCS Consulting & Construction Co. Inc.
Ted Sofis | Sofis Company Inc.
Marcus H. von der Hofen | Coastal Gunite Construction Co.
Ezgi Yurdakul | GCP Applied Technologies

championship golf course (a current stop on the PGA Tour), a Napa Valley Wine Cave Tour, and other local attractions.

The event will culminate on the evening of Tuesday, March 13, with the annual ASA Outstanding Shotcrete Projects Awards Banquet, to be held at nearby historic Inglenook Winery. This event will replace the banquet held previously at World of Concrete and will provide a great opportunity for networking and to celebrate the progress and excellence our industry enjoys.

As with all industry events, success of our event will not only be attributed to the behind-the-scenes work of ASA staff and active committee members, but also to the generosity of its member companies and supporters. The ASA task group for meeting sponsorships has established two levels of sponsorship: a $1000 Silver Sponsorship and a $2500 Gold Sponsorship. In addition to contributing to the success of ASA's first technology conference, sponsors will receive the following benefits:

- Company logo on signage at the event;
- Recognition in the Awards Issue of *Shotcrete* magazine;
- Recognition in the event and awards banquet program;
- Company logo in the awards banquet presentation;
- Recognition on the ASA website;
- Recognition at ASA's booth at World of Concrete 2018 in January; and
- Tabletop booth in the exhibit area at Silverado Resort and Spa (Gold Sponsors only).

A task group has been set up to solicit sponsorship commitments from as many of our ASA member companies as possible but please don't wait for a phone call. Sponsorship forms are now available on the ASA website. The generosity of our Association members across the shotcrete industry has been legendary and ASA will once again count on that generosity to make this event the success we believe it can be.

Registration information is available now on the ASA website and is also included in this edition of *Shotcrete* magazine. Space will be limited, so please register soon and take advantage of the sponsorship opportunities offered for this ASA 20th Anniversary event.

Looking forward to seeing everyone in Napa in March!

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EXECUTIVE DIRECTOR UPDATE

Spreading the Word…

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

Those of you who have followed my updates over the last couple of years have noticed that ASA is making remarkable headway in outreach to owners, specifiers, professors, students, and even standards developing organizations (SDOs) such as ACI and AREMA. We're spending time in front of these groups in face-to-face seminars (both 1-hour and full-day sessions), online webinars, concrete conferences, and SDO committee meetings.

Fortunately, I've been able to present or participate in many of these outreach efforts. It is hard to explain how fulfilling it is to walk into a room of engineers, who usually know a little bit about shotcrete but often have reservations or misconceptions, and open their eyes to the quality, creativity, versatility, and durability of shotcrete. Members of our Marketing Committee (chaired by Joe Hutter), our Underground Committee (chaired by Axel Nitschke), our Education Committee (chaired by Oscar Duckworth), and our Contractor Qualification Committee (formerly chaired by Chris Zynda, and now chaired by Marcus von der Hofen) have spent considerable time and effort in developing core presentations on:

- Introduction to Shotcrete (±1 hr);
- Shotcrete for Underground Applications (±1 hr);
- Shotcrete Inspector Education (±7 hr); and
- Shotcrete Contractor Education (±7 hr).

The Shotcrete for Underground Applications presentation has just been finished by our Underground Committee and approved by the Board. The first presentation is scheduled in November as a webinar to a Younger Member Group of the UCA of SME. We are also on ACI's national Chapter Activities list of topics for presentation at ACI Chapter meetings. We have also put together custom presentations upon request for presentation at conferences or events. Examples include our presentation this summer at PCA's Professors Workshop, a presentation to the National Concrete Consortium with representatives from over 35 DOTs, presentations to the well-attended Annual Concrete Conferences in New York and Minnesota, and ConAgg/ConExpo this spring.

Our Safety Committee, chaired by Andrea Scott, along with our Education Committee, chaired by Oscar Duckworth, are both well along in development of a 2- to 3-hour seminar on shotcrete safety. The target audience for this presentation is our shotcrete craftsmen and contractors. We look forward to rolling out this program in 2018.

We also have targeted outreach to students, making funds available for ASA speakers to present at universities around the United States and Canada. Both Frank Townsend, one of our Board members, and I have presented at several universities to Civil Engineering and Construction students. We want to increase this program significantly, so if you have any contacts at a school with engineering or construction who may be interested in a presentation, please call 248-848-3742 or send me an e-mail (charles.hanskat@shotcrete.org) with the contact information.

Tradeshows continue to be a big part of our outreach. We have exhibited at the annual World of Concrete show for many years and are co-sponsors of the show (remember to **use the ASA code A17** when registering for WOC 2018). However, we increased our tradeshow schedule this year with an exhibit at the Railway Interchange 2017 in Indianapolis, IN, in September and the International Pool | Spa | Patio show in Orlando, FL, in November. Although we may not sign up a lot of new members at these shows, it is a great opportunity to promote to owners and specifiers that the concept of shotcrete is a valuable method for concrete construction and repair.

Another avenue for outreach is working with various SDOs to get shotcrete recognized and adopted as part of concrete industry codes, specifications, and standards. ASA is working with ACI Committees such as 301, 318, 562, and 563 to inform the committee members about shotcrete and to assist in the development of provisions that accurately represent the needs of quality, durable shotcrete in a wide variety of concrete structures. We also work with ASTM Committee C09.46 on shotcrete-related testing and material standards, and the American Railroad Engineering and Maintenance-of-Way Association (AREMA) on shotcrete provisions in their Manual of Railway Engineering.

Finally, *Shotcrete* magazine has become the most respected and credible source of information about our industry. We reach over 17,000 readers around the world with this quarterly publication. The contributions of our members, in articles and columns, as well as financially through advertising, are what keeps our publication current and truly representative of the growing construction market that is shotcrete. Our ASA staff members, Alice McComas and Beth Hinman, as well as Susan Esper in the ACI Publishing Services Department, spend countless hours every issue to make *Shotcrete* magazine the professional magazine that we enjoy.

But we can do more. Can you help us spread the word? If you know of an engineering firm, owner interested in shotcrete, DOT, testing lab, or university who would benefit from one of our presentations, please contact me (charles.hanskat@shotcrete.org) or send them to the Onsite Seminars page on **www.shotcrete.org** under the Products/Services & Information tab for more information. If you know someone who would benefit from a free subscription to *Shotcrete* magazine, send them to the same tab on the website and *Shotcrete* magazine/Subscribe to sign up. A great benefit of being part of ASA is that together we can extend our reach much further than any individual can achieve. Working together through ASA, we can spread the word about the quality, durability, economy, creativity, and versatility of shotcrete placement in a wide variety of concrete construction.

SHOTCRETE CALENDAR

NOVEMBER 15-17, 2017	**International Concrete Repair Institute Fall Convention** Hyatt Regency Hotel | New Orleans, LA **www.icri.org**
DECEMBER 3-6, 2017	**ASTM International Committee C09, Concrete and Concrete Aggregates** Sheraton New Orleans | New Orleans, LA **www.astm.org**
DECEMBER 3-8, 2017	**American Exploration & Mining Association Annual Meeting & Exhibit** Nugget Casino Resort | Sparks (Reno), NV **www.miningamerica.org**
JANUARY 11-12, 2018	**Shotcrete 2018** Alpbach Conference Centre | Tyrol, Austria **www.spritzbeton-tagung.com**
JANUARY 22, 2018	**ASA Meetings at World of Concrete** Las Vegas Convention Center | Las Vegas, NV **www.shotcrete.org**
JANUARY 23, 2018	**ASA Shotcrete Nozzleman Education** WOC Registration Code: ASATU (English) WOC Registration Code: ASASTU (Spanish) NEW! Las Vegas Convention Center | Las Vegas, NV **www.shotcrete.org**
JANUARY 23-25, 2018	**The Pool & Spa Show 2018** Atlantic City Convention Center | Atlantic City, NJ **www.nespapool.org**
JANUARY 23-26, 2018	**World of Concrete 2018** Visit ASA Booth #10938 Register with ASA source code: A17 Las Vegas Convention Center | Las Vegas, NV **www.worldofconcrete.com**
JANUARY 24, 2018	**CICL Application of Shotcrete Course offered in Spanish** WOC Registration Code: CICLE Las Vegas Convention Center | Las Vegas, NV **www.shotcrete.org**
JANUARY 25, 2018	**ASA 90-minute Shotcrete Seminar:** **Advanced Shotcrete Techniques for Architectural & Structural Projects** WOC Registration Code: TH147 Las Vegas Convention Center | Las Vegas, NV **www.shotcrete.org**
MARCH 11-13, 2018	**ASA 20th Anniversary Event: First ASA Shotcrete Convention** Silverado Resort and Spa | Napa, CA **www.shotcrete.org/20thanniversary**
MARCH 25-29, 2018	**The ACI Concrete Convention and Exposition** Theme: “Concrete Elevated” Grand America & Little America | Salt Lake City, UT **www.concrete.org**
WANT MORE INFORMATION?	**See a full list with active links to each event: visit www.shotcrete.org and click on the Calendar link under the News & Events tab.**

A History of Shotcrete in Refractory

By Ted W. Sofis

The Early Years of Refractory Gunning

It wasn't long after Carl Akeley developed the dry-mix process (originally trademarked by the Cement Gun Company as "gunite") in the early 1900s that dry-mix started to be used for the fireproofing of mines. The earliest refractory gun mixtures were proportioned and mixed in the field. Mixtures such as the 1-2-4 mixture were widely used for industrial ductwork and petrochemical applications. The 1-2-4 mixture consisted of one part lumnite, or calcium aluminate cement; two parts haydite, an expanded shale; and four parts vermiculite. These early refractory mixtures were mixed on the ground or with paddle mixers—on jobsites—and they provided a low-density insulating refractory that could be gunned in place and handle the high temperatures.

Dry-Mix Gunning Materials

Manufactured refractory mixtures date back to the 1930s, but they were generally mixtures made for cast-in-place applications. In those days, gunning castables usually involved pre-dampening and aging the material for a period of time prior to gunning to get a successful result. In the 1960s, ball clays and chemical additives were incorporated into the refractory mixtures to help the material hang better and stay in place. The ball clays gave the mixture a sticky quality and chemical additives aided set times. A good gun mixture needed to have enough sharp aggregate to keep the gunning hoses clean from buildup and enough clay to help hold the material in place until it began to set. In the 1970s, gun mixtures were refined further to widen the water threshold and rebound was greatly reduced. Gunning products quickly gained acceptance in the steel industry for addressing refractory wear areas in steel ladles, soaking pits, and furnaces.

The speed of installation soon led to the use of monolithic gunned refractory materials in blast-furnace troughs, blast furnaces, and many other applications.

Steel Mill and Industrial Applications

I personally began working in the shotcrete industry gunning refractory in steel teeming ladles. After a teeming ladle finished emptying its steel into molds, the empty ladle would be laid on its side and a thin layer of clay-based refractory would be gunned on red glowing ladle brick. This thin refractory coating would instantly dry on contact. When a ladle went off for repairs, we would take advantage of the opportunity to gun the ladle with a thicker application. The refractory coatings would extend the life of the ladle brick from 17 heats per ladle to 50 or 60 heats. In 1975, we worked with the first spinner prototype for gunning ladles. The spinner gun was a rotating nozzle system that was lowered into

A 9 in. (225 mm) thick dry-mix process installation of high-strength 2600°F (1400°C) refractory in a power plant ash hopper

Gunning a high-temperature refractory with the dry-mix process in the burners of a coal-fired power plant. The refractory material did not use portland cement the upright ladle to enable the operator to shoot ladles by remote control.

In blast-furnace departments, we would routinely gun refractory materials to reline the blast-furnace troughs. Because the refractory gunning could be performed quickly, blast-furnace down time was greatly reduced. This enabled the blast furnace to get back on line quicker and possibly get an additional cast in that day. In steel making, lost production time is expensive and can often be costlier than the repair work.

In the power industry, gunned monolithic refractories began to replace fire brick in power plant ash hoppers. Large boiler design and engineering companies such as Babcock & Wilcox and Combustion Engineering developed their own refractory gun mixtures, including a prepackaged version of the old 1-2-4 mixture.

A variety of specialty gunned refractory materials, including high-strength refractories for ash hoppers; chrome alumina, for cyclones; and medium-density and lightweight insulating gunning mixtures, are currently used in power generation facilities.

"Hot gunning," common in the steel industry, is where gunning repairs are made to vessels, soaking pits, or coke ovens while the units are still hot. These gunning repairs can be done with a handheld lance or with a remotely operated nozzle.

ADVANCES IN DRY-MIX GUNNING EQUIPMENT

Initially, most of the refractory maintenance gunning was done with single-chamber, batch-type guns, where the gun was loaded with material, pressurized, and then the material discharged. The development of the continuous-feed rotary gun (National Foundry's Jet-Creter, a straight drop rotary gun with a rotating air lock) opened refractory shotcrete to greater use in the steel industry.

The Reed Gun that followed was the first bowl-type continuous-feed rotary gun to be widely used for refractory gunning. The Reed Gun gained popularity in the mid-1970s because it was easy to use and small enough to be stationed at various steel mill locations where maintenance gunning was done on steel ladles, blast-furnace departments, and soaking pits. Pre-dampening of the prepackaged refractory materials was initially accomplished with paddle mixers. This required adding a premeasured amount of water, mixing for a few minutes, dumping the mixture out of the mixer, and hand shoveling the dampened material into the gun. Allentown developed a gunning system with a mixer, conveyor, and hopper, and provided a method to pre-dampen without having to double-handle the material. In the 1970s, auger-type pre-dampeners emerged, most notably the Reed-Mate and the B & B Pre-dampener. They provided a more efficient means of pre-dampening dry packaged refractory material.

In my time in the business, I worked through the early years using paddle mixers, then the conveyor hopper rigs, and on to the auger type pre-dampeners that we still use today.

The Jet-Creter was the first straight-drop rotary gun used for refractory installations in the United States. They typically had gasoline engines to run the rotor and were mounted on wheels with a trailer hitch for towing

An auger-type pre-dampener used in dry-mix process refractory installations

A typical setup used in dry-mix process refractory installations with a rotary gun and an auger-type pre-dampener for gunning dry prepackaged refractory material

WET-MIX PROCESS SHOTCRETE REFRACTORY

The emergence of wet-process shotcrete for refractory installation lagged behind the civil and building industries for a few reasons. First, the technology in refractory shotcrete pump mixtures had not yet been developed. That work was first undertaken at Harbison Walker in the mid-1990s. The patent was applied for in 1996, by inventors Mark C. Langenohl and Gustav O. Hughes, for "non-slumping, pumpable, castable, and method of applying same" for shotcrete application. Another obstacle was mixing dry, pre-packaged refractory materials quickly enough to keep pace with concrete pumping. The existing refractory mixing equipment, at the time, was not adequate to mix and handle a volume of material that could be pumped. Early installations used continuous mixers or a dedicated concrete truck to mix the refractory materials. This problem was later overcome with the development of turbine-style pan mixers with high-speed mixing blades.

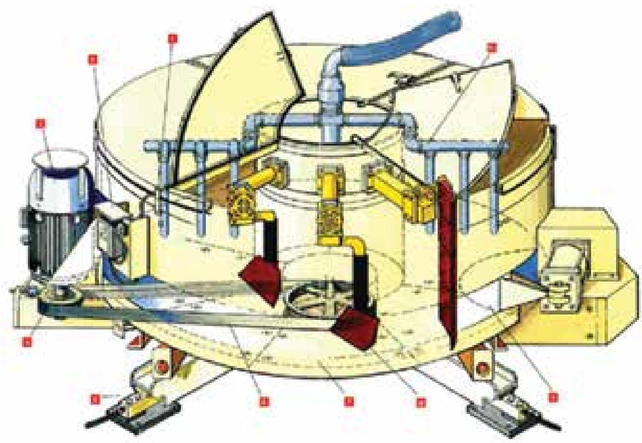


Diagram of a turbine mixer. The wet-mix process didn't become viable for refractory installations until the 1990s, when mixers were developed that could mix quickly enough to keep pace with the higher-volume wet-mix shotcrete pumps

Wet-mix shotcrete pump with a pan mixer for handling bulk sacks works well for mixing and placing large volumes of material

The pan mixers and the new technologies in pumpable shotcrete refractories opened the door to high-volume wet-process shotcrete installations.

ROBOTIC SYSTEMS

The progression to robotic systems for remote manipulation of the nozzle created many innovations. In years past, hot gunning was mainly done with long, handheld lances and protective clothing. The major problems with hot gunning by hand involved contending with the intense heat and the difficult and awkward gunning angles. Today, with the technology available, basic oxygen furnace vessels can be shot with robotic systems. Visibility in hot vessels and the intensity of the high temperatures present major difficulties. However, these issues can be effectively dealt with by using a computer-programmed robotic gunning system. The areas in need of repair are located by a laser that scans the inside of the vessel. The nozzle is then directed to these areas where the refractory material is gunned in place. The refractory material can be efficiently installed without the exposure and difficulties of using a handheld nozzle.

LOOKING FORWARD

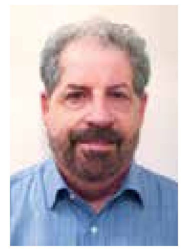
Refractory mixtures continue to evolve. In recent years, ultra-low-cement gunning mixtures have become more common. There are ultra-low-cement gun mixtures for the dry-mix process gunning and ultra-low-cement pump mixtures for wet-mix shotcrete. Refractory gun mixtures with no cement, with enhanced refractory properties, have been introduced and are being used effectively in a variety of applications.

Refractory-lined 0.25 mile (0.4 km) long tunnel was placed with shotcrete

In the 42 years that I've been involved in gunning refractory, we've seen substantial advances. I've had the good fortune to work with many talented, dedicated, and innovative people in both the material and equipment sides of refractory applications. When we had problems gunning, they listened and made adjustments with grain sizing and other aspects of their mixtures to make better gunning refractory products. It's remarkable how far we've come and how much progress has been made in such a short time. With the 20th anniversary of the American Shotcrete Association, it is fitting to look back at the progress we've made in the rather specialized refractory shotcrete business and detail the accomplishments we've made along the way.

Acknowledgments

Gus Hughes, President, Mt. Savage Specialty Refractories.



__Ted Sofis__ and his brother, William J. Sofis Jr., are the Principal Owners of Sofis Company, Inc. After he received his BA in 1975 from Muskingum College, New Concord, OH, Ted began working full time as a shotcrete nozzleman and operator servicing the steel industry. He began managing Sofis Company, Inc., in 1984 and has over 40 years of experience in the shotcrete industry. He is Chair of the ASA Publications Committee, a member of multiple other ASA committees, and an ACI Examiner. Over the years, Sofis Company, Inc., has been involved in bridge, dam, and slope projects using shotcrete and refractory installations in power plants and steel mills. Sofis Company, Inc., is a member of the Pittsburgh Section of the American Society of Highway Engineers (ASHE) and ASA.

Evolution of Shotcrete Materials in the Past 20 Years

By Nicolas Ginouse and Simon Reny

Shotcrete has evolved significantly since the early 1900s. We've certainly achieved remarkable progress since the early 1980s when volumetric batching of sand and cement was the norm. This simple technology had its uses, but volumetric batching often led to inaccurate (and usually high) cement contents. High cement contents, combined with a lack of coarse aggregate, resulted in high shrinkage values, resulting in increased cracking potential and porosity. Advances in traditional cast concrete mixture designs have translated well to mixtures placed using the shotcrete process. In this article, we discuss the evolution and sophistication of shotcrete materials primarily governed by industry demand for high-quality, durable, and robust solutions for a wide range of new construction, repair, retrofit, and ground support applications. New chemical admixtures, additives, pozzolan, and cement technology have provided numerous technological breakthroughs for the shotcrete industry. The shotcrete industry has embraced

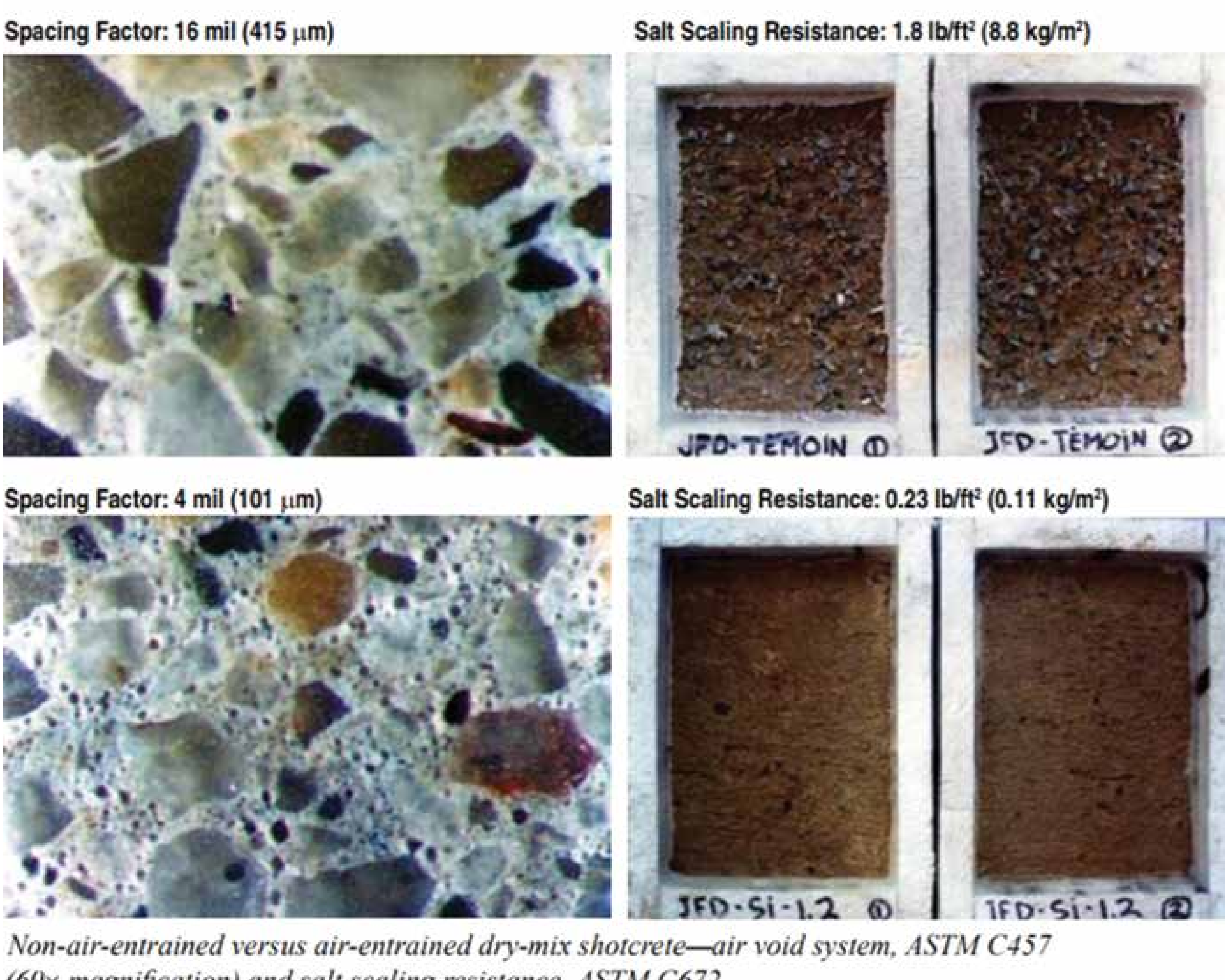


Fig. 1: Effect of air-entraining in dry-mix shotcrete[2]

these technological breakthroughs and left the old sand and cement days, with all its potential weaknesses, behind.

Powder Air Entrainment

In 1996, the addition of air entrainment in wet-mix shotcrete was not new. However, the introduction of powder air-entraining admixtures in the dry-mix shotcrete was a new phenomenon. It was widely assumed that dry-mix shotcrete durability could only be achieved with silica fume, proper compaction, and low water-cement ratio (*w/c*) (all of which resulted in low permeability). Studies completed at the University of Laval in Quebec City, QC, Canada, however, proved that the addition of air entrainment in dry-mix shotcrete was not only feasible but it also consistently provided significantly improved long-term durability.[1] Figure 1 shows how dramatically salt scaling resistance can be improved using proper dosages of air-entraining additives, which stabilized air void systems and reduced the air void spacing factors.[2] This technology has been adopted by many Specifiers, especially those in northern climates where concrete structures are exposed to extensive freezing-and-thawing cycling. Since 1996, thousands of structures throughout North America have been successfully repaired using dry-mix shotcrete mixtures that are enhanced with powder air-entraining admixtures.

Macro-Synthetic Fibers

Although high-volume macro-synthetic fibers were used in wet-mix shotcrete applications as far back as 1988, and even earlier for concrete slab applications, the length and shape of macro-synthetic fibers made them impractical for dry-mix applications. The use of macro-synthetic fibers adapted well to wet-mix shotcrete formulations, primarily because of the similarities in the mixture design, but as reported by Morgan and Rich[3] in 1998, attempts to use macro-synthetic fibers in dry-mix shotcrete applications failed for a variety of technical reasons. To adapt macro-synthetic fibers to the dry-mix shotcrete process, it took almost another decade of research. Dufour et al.[4] developed a solution that was immediately adopted by some Canadian mines to improve flexural toughness and reduce wear on shotcrete equipment. In the construction of the pedestrian tunnel connecting Billy Bishop Island Airport to the mainland in downtown Toronto, ON, Canada, macro-synthetic fibers were chosen over steel fibers to avoid compromising the waterproof membrane (Fig. 2), as reported by Croutch.[5]

Impact and Abrasion Resistance

Over the past 20 years, many studies have been completed to improve the resistance of shotcrete linings to impact and abrasion. Primary applications included mining industry examples such as ore pass and ore bin linings. Other applications included the rehabilitation of cold climate lighthouses and other marine structures subject to impact by ice flows. Studies proved that dry-mix shotcrete applications using an optimized mixture design, combining the proper cementitious matrix with hard aggregates and steel fibers at the optimum dosage, provided a durable protective lining even if exposed to aggressive abrasion and impact.

These high-performance dry-mix shotcrete mixtures were first used to repair a lighthouse on the St. Lawrence River (as reported by Gendreau et al.[6]), and the technology has gained acceptance on numerous other high-impact or high-abrasion applications. Ease of application and long-term performance led to its use on numerous projects across North America.[7] Today, most ore passes in Canadian mines are excavated and lined using high-performance, high-dosage, steel-fiber shotcrete to ensure the long-term performance of these critical infrastructures[8] (Fig. 3).

Self-Consolidating Wet-Mix Shotcrete for Mining Applications

After the development of flowable/pumpable self-consolidating concrete, similar wet-mix shotcrete materials were

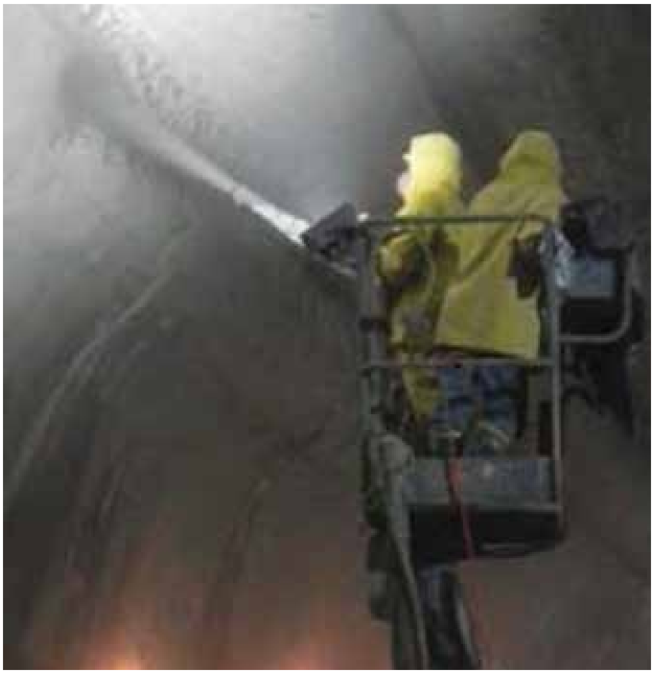


Fig. 2: Application of macro-synthetic fiber shotcrete in the Billy Bishop Pedestrian Tunnel[5]

Fig. 3: Construction and installation of protective shotcrete lining for critical ore pass in a Northern Quebec gold mine

introduced in 2003 at deep, hard rock mines in Québec, Canada, to address material delivery challenges.[9] For these applications, shotcrete mixtures were mixed on the surface before being dropped several thousand feet (m) through a steel pipe (slick line) and then transferred to an agitator truck for underground delivery and placement. This innovative solution was possible using advanced technology high-range water-reducing admixtures, viscosity modifiers, and hydration control admixtures and significantly increased shotcrete placement production at these depths. The development and application of these admixtures for mining and tunneling applications undoubtedly contributed to the increased use of wet-mix shotcrete.

These advanced admixture technologies have expanded into preblended, prepackaged, self-consolidating wet-mix materials, supplied in bulk or bagged formats. This technology, where all components are preblended in dry form, provided further flexibility and allowed shotcrete crews to produce their own shotcrete "on demand," simply by adding water to the dry, preblended material[10] (Fig. 4). These products have been successfully used in many operating mines across North America.

ULTRA-RAPID-STRENGTH DRY-MIX SHOTCRETE

Initially introduced in Canada in 2013 for mining applications, ultra-rapid-strength dry-mix shotcrete was developed to accelerate the underground development cycle (drill, blast, muck, shotcrete) to improve productivity. Shotcrete mixtures produced with this new technology provide—in only 2 hours—the same 24-hour compressive strength values achieved with portland cement-based shotcrete mixtures[11] (Fig. 5). This innovative technology combines a shotcrete mixture using a very reactive ettringite-based cement using the dry-mix process and allows proper and consistent placement without the risk of blocked hoses. This technology has also been combined with macro-synthetic or steel fibers to overcome challenging ground support applications and to provide more rapid impact and abrasion resistance solutions.

ENGINEERED HIGH-PERFORMANCE, FIBER-REINFORCED DRY-MIX SHOTCRETE

Initially developed and used in Japan for civil applications, this technology was introduced in Canada a few years ago for mining applications in areas of considerable seismic activity and extremely poor ground conditions. In many of these situations, conventional fiber-reinforced shotcrete possessed limited effectiveness due to poor resistance to spalling under these conditions (Fig. 6). The extremely high flexural and tensile toughness provided by this innovative mixture design technology has provided an effective protective lining for areas affected by blasting.[12]

SUSTAINABLE DRY-MIX SHOTCRETE USING SUSTAINABLE MATERIAL

As in traditional concrete mixtures, sustainable and recycled materials including aggregates,[13] recycled glass filler, blast-furnace slag, plastic (Fig. 7), rubber (Fig. 8), and others[14] have been shot using the dry-mix shotcrete process. By nature, dry-mix shotcrete does not require pumpability as a mixture characteristic and therefore provides a unique ability to

Fig. 4: Mobile concrete mixing unit integrated with a lifting system for bulk, preblended concrete, and shotcrete material bags[10]

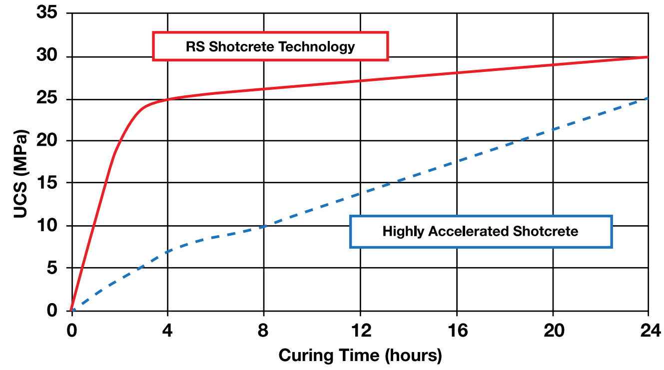


Fig. 5: Typical strength development curve of King RS Shotcrete Technology versus highly accelerated portland-cement-based shotcrete[10]

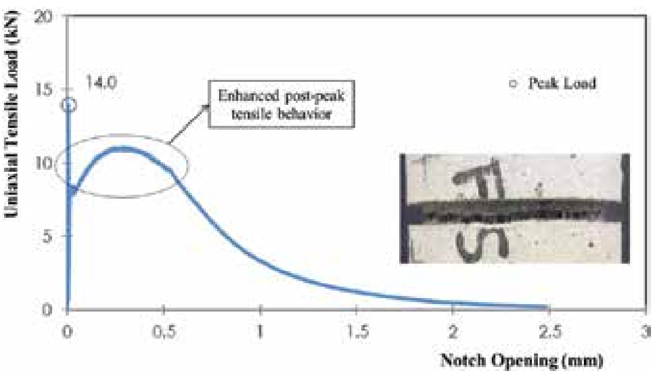


Fig. 6: Post-peak tensile behavior of an engineered high-performance fiber-reinforced dry-mix shotcrete[11]

spray extremely complex materials. Many of these materials would be impossible to pump with a conventional concrete pump due to their high viscosity, rapid reactivity, or unstable rheology. Current research is developing analysis tools that can evaluate the environmental impact of shotcrete mixtures with the objective to optimize sustainability.

Development of Highly Crack-Resistant Shotcrete

When used in repair, shotcreted materials can be subjected to high restrained shrinkage conditions. Shotcrete's ability to accommodate the restraint without cracking is critical to ensuring long-term durability. There are a limited number of testing methods to evaluate cracking potential of cast concrete or mortars. These test methods designed for casting materials require modification to make them suitable for concrete placed using the shotcrete process. Recent studies detail the adaptation of existing test methods to shotcrete mixtures to determine crack resistance of the material as shot.[15] The test method uses molds in ring form as per AASHTO T 334 (Fig. 9 and 10) and reproduces restrained shrinkage conditions. The development and use of this test method for shotcrete paves the way for mixture design optimization and improvement of the crack resistance and durability of shotcrete materials.

Fig. 7: Shotcrete core containing shredded recycled plastic[14]

Fig. 8: Shotcrete core containing recycled rubber beads[14]

Conclusions

Over the past 20 years, new shotcrete materials technology has evolved faster than in the previous 100 years. These technological developments have produced dramatically improved quality and superior performance of shotcreted materials. This evolution of materials has served the shotcrete industry well, and together with advancements in equipment design, improved training and education, certification of shotcrete nozzlemen, and recognition of qualified shotcrete crews and contractors

Fig. 9: Sketch from the AASHTO T 334 restrained ring test[15]

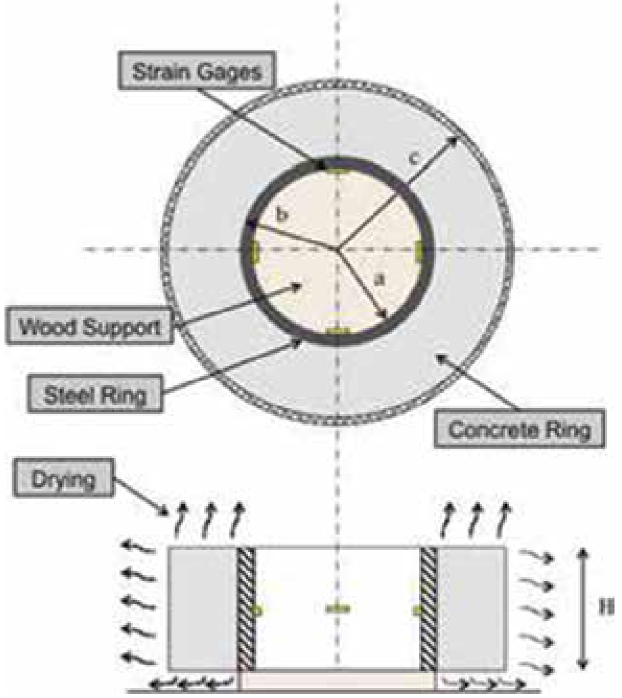


Fig. 10: Modified AASHTO T 334 restrained ring test orientation during shooting allows proper consolidation of the test specimen[15]

has led to sizable growth in the shotcrete industry. Moving forward, our industry must take advantage of these new, commercially available and innovative shotcrete materials and technologies. Most of the technologies presented in this brief article have been used successfully and are lightyears ahead of the old sand/cement mixtures developed at the beginning of the 20th century.

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A Brief History of Shotcrete in the Underground Industry

By Dudley R. (Rusty) Morgan and E. Stefan Bernard

It is now generally recognized that Carl Ethan Akeley (1864-1926) was the inventor of shotcrete (Teichert 2002). The process was originally developed for application of plaster to rehabilitate the façade of a building at the Field Columbian Museum in Chicago, IL, but was soon used to apply cementitious materials to various substrates, including wire and cloth substrates for building anatomical models of animals for museum exhibits. The gun invented by Akeley (Fig. 1) operated on the principle of a double chamber. The chambers were placed one on top of the other and were alternatively pressurized with compressed air. One of its earliest underground uses was for lining the Hunter's Brook Siphon for New York Water Supply.

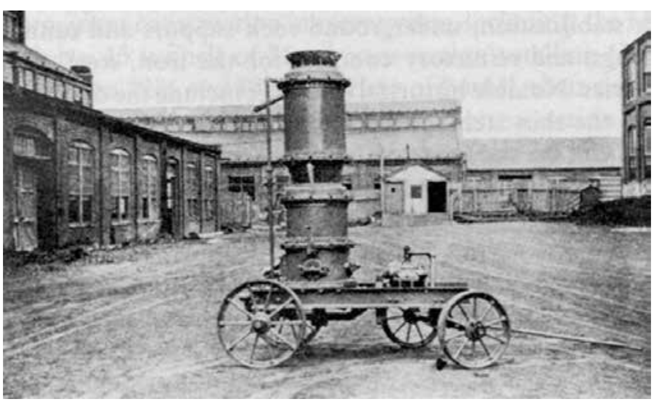

Fig. 1: Original double-chamber gun developed by Carl Akeley in 1907

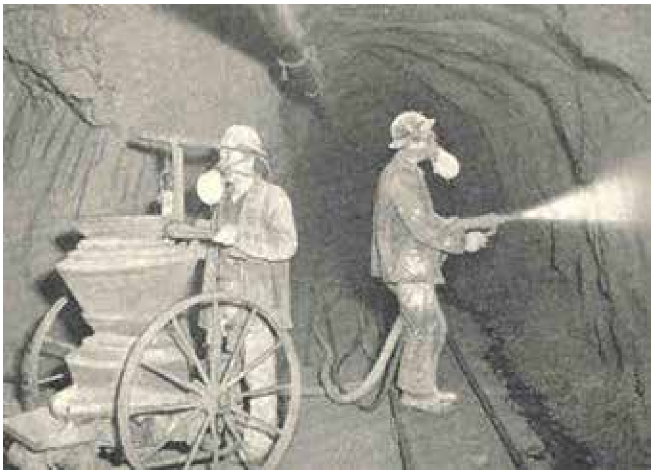

Fig. 2: Lining a tunnel with gunite using a double-chamber gun in the 1920s

In 1912, the Cement Gun Company in Allentown, PA, acquired the rights to Akeley's patents for the cement gun and trademarked "gunite." The gunite process found use in a wide variety of applications, including lining of sewer, water, and railway tunnels; ground support in mines; construction and repair of buildings; protection of structural steel against corrosion and fire damage; repair of bridges, dams, and canals; rock slope stabilization; and construction of water-retaining structures.

By the early 1920s, the use of gunite (Fig. 2) was widespread throughout North America and had expanded to Germany (1921), the United Kingdom (1924), and by the end of the decade, to other countries in Europe as well as India and South Africa. The use of the gunite process continued to expand throughout the world during the 1930s and 1940s, with the double-pressure chamber gun the predominant method for material delivery.

In the early 1930s, the American Railway Engineering Association adopted the term "shotcrete" to describe the dry-mix process and in 1951, the American Concrete Institute (ACI), to standardize terminology, also adopted the term "shotcrete." Initially, the term "shotcrete" applied only to the dry-mix process, but after World War II, with the development of the wet-mix process, ACI adopted the term "wet-mix shotcrete." In Europe, the term "sprayed concrete" is generally used instead of shotcrete.

MAJOR DEVELOPMENTS IN TECHNOLOGY

The development of shotcrete and its application in underground construction has been improved through the advent of a succession of key technologies. These include:

Wet-Mix Shotcrete

A major revolution in the shotcrete industry occurred with the development of the wet-mix shotcrete process. Various individuals and companies had experimented with this process as far back as the 1920s (Sprayed Concrete Association 1999), but it was not until the mid-1950s that the wet-mix process started to find significant application. Numerous equipment manufacturers modified concrete pump designs to make them better suited to wet-mix shotcrete application. It was primarily the development of the swing-tube concrete pump in the late 1970s (Fig. 3) that really made wet-mix shotcrete practical (Yoggy 2002). The cylinders were sized to make them suitable for conveying shotcrete at a rate that could be managed by a nozzleman for hand application. The rate of cycling of the swing tube controlled the surge and volume of shotcrete delivered per minute. With these refinements, the nozzleman could maintain precise control over placement of concrete in a wide range of different shooting conditions (for example, vertical, overhead, downward, open shooting, or shooting congested reinforcing steel and embedments) at a rate of productivity of about four times what was possible by the dry-mix shotcrete process. With the subsequent introduction of robotic manipulators in Norway (Woldmo 2008), which typically used bigger pumps and larger-diameter hoses, even greater rates of production were achievable. These machines are now used throughout the world.

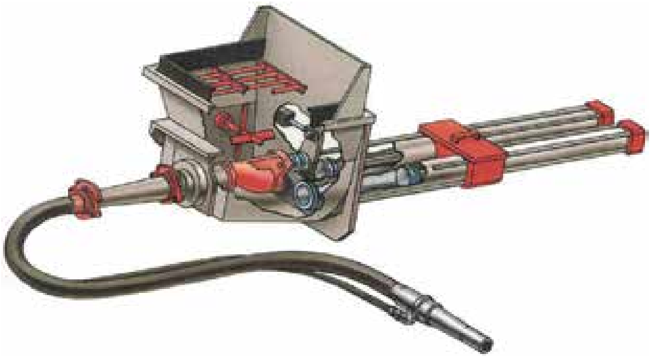

Fig. 3: Schematic of a wet-mix shotcrete pump with swing tube

Fig. 4: Dry-mix steel FRS lining of a railway embankment in Burnaby, BC, Canada, in 1978

Steel Fiber Reinforcement

The concept of reinforcing shotcrete with discreet, discontinuous fibers was first developed by the Batelle Research Corporation in the United States in 1971 (Morgan 2000). The first practical application of steel fiber-reinforced shotcrete (FRS) in North America was in 1972, when it was used by the U.S. Army Corps of Engineers for rock slope stabilization and lining a tunnel adit at the Ririe Dam on Willow Creek, a tributary of the Snake River in Idaho (Kaden 1974). The first use of steel FRS in Canada was in 1978, when it was used to stabilize a sloughing railway embankment in Burnaby, BC, Canada (Fig. 4).

Synthetic Fiber Reinforcement

Synthetic fiber-reinforced shotcrete first appeared in the 1990s as manufacturers developed products to compete with steel fibers (Bernard et al. 2014). There are basically two types of synthetic fibers: microfibers and macrofibers. Microsynthetic fibers can be used in both wet- and dry-mix shotcretes, but macrosynthetic fibers are mainly used in wet-mix shotcrete. Microsynthetic fibers are typically used at low addition rates of 1.7 to 3.4 lb/yd^3 (1 to 2 kg/m^3) to improve resistance to plastic shrinkage cracking, but in shotcrete they have primarily been found effective in increasing resistance to explosive spalling in tunnel linings subjected to high-temperature fires (Tatnall 2002). Macrosynthetic fibers are used at much higher addition rates of 5 to 15 lb/yd^3 (3 to 9 kg/m^3) and are employed for many of the same reasons as steel fiber reinforcement—for example, to improve toughness (residual load-carrying capacity after cracking) and impact resistance (Morgan et al. 1999; Morgan 2000).

Silica Fume

A milestone in the development of shotcrete technology was the incorporation of condensed silica fume as a supplementary cementitious material in the shotcrete mixture. This was first undertaken in Norway in 1975 (Garshol 1990). The first application of silica fume in shotcrete in Canada was in 1984, when it was used in shotcrete rehabilitation of a pier in the intertidal region in Vancouver Harbour, BC, Canada (Morgan 1995). It was found that the use of silica fume had major benefits, including enhanced adhesion and cohesion, with reduced rebound and fallout in the plastic shotcrete and increased strength and durability in the hardened shotcrete.

Air-Entraining Admixtures

Air-entraining admixtures have been used in wet-mix shotcrete to provide freezing-and-thawing durability since the development of wet-mix shotcrete in the mid-1950s. Research at Laval University in Quebec, Canada, in the late 1980s and early 1990s showed that it was possible to entrain sufficient air in dry-mix shotcrete to provide good freezing-and-thawing durability and resistance to deicing salt scaling (Beaupre et al. 1994). Currently, most dry-bagged shotcrete materials for exterior applications in frost exposure environments are batched with dry powdered air-entraining admixtures (Vezina 2001).

Water-Reducing Admixtures

Conventional water-reducing admixtures have been used in wet-mix shotcretes since the 1950s. However, with the introduction of silica fume into shotcrete applications in North America in the mid-1980s, the use of conventional water-reducing admixtures alone was often insufficient to reduce water demand to the extent needed to provide a suitably low water-binder ratio (*w/b*). Therefore, in the mid-1980s, high-range water-reducing admixtures (also called superplasticizers) started to be used in conjunction with conventional water-reducing admixtures in wet-mix silica fume shotcretes.

Retarders and Hydration Controlling Admixtures

Wet-mix shotcretes typically take longer to discharge from transit mixers than conventional concretes because of the requirement to control the rate at which shotcrete is supplied to the nozzle. Thus, set-retarding admixtures have often been added to wet-mix shotcrete mixtures to extend the workability (pumpability) of the mixture, particularly in hot weather conditions. Conventional set retarders have, however, had their limitations, particularly in tunnel and mining applications, where there are often long delays (sometimes 4 to 8 hours) from the time of batching to completion of discharge of the shotcrete. The introduction of hydration controlling admixtures in the 2000s had a major beneficial effect on the shotcrete industry. It is now possible to put the shotcrete "to sleep" for 12 hours (or even longer, if required) and then instantly wake it up with shotcrete accelerator addition at the nozzle.

Shotcrete Set Accelerators—Underground

Shotcrete set accelerators are an essential component of shotcrete in underground applications, particularly for overhead applications in tunnels and mines. In dry-mix shotcrete, they can be added either as dry powdered

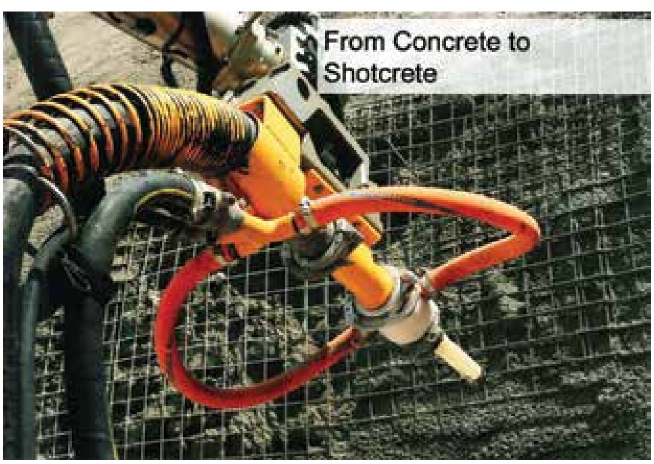

Fig. 5: Accelerator addition at nozzle in remote control wet-mix shotcrete

Fig. 6: Hand application of dry-mix shotcrete in a tunnel in British Columbia, Canada, in the 1970s

materials to the dry-mix shotcrete materials before introduction into the shotcrete gun, or as liquids added at the shotcrete nozzle. In wet-mix shotcretes, they are added as liquids at the shotcrete nozzle (Fig. 5). Early (circa 1960s to 1990s) dry-mix shotcrete accelerators were mainly highly alkaline (>12 pH) sodium or potassium-aluminate-based dry-powdered products, or liquid-alkaline-sodium-silicate-based products. These tended to have detrimental effects on the longer-term compressive strength, permeability, and durability of the shotcrete, with the effect being more pronounced the greater the accelerator addition rate. A major advance in shotcrete technology was the introduction in the 2000s of so-called "alkali-free" shotcrete accelerators. These liquid accelerators are mainly based on aqueous solutions or suspensions of aluminum sulfate compounds and have a pH of approximately 3. They have less negative effect on the compressive strength, permeability, and durability of shotcrete (Millette and Jolin 2014) and are compatible with most hydration-controlling admixtures. They are now used widely throughout the world in underground applications.

SHOTCRETE IN TUNNELS

The first reported use of shotcrete for underground support in North America was the use of gunite (dry-mix shotcrete) in the Brucetown Experimental Mine in 1914. It was used primarily to protect and maintain excavated rock surfaces from deterioration from exposure to water and air (Kobler 1966). Thereafter, for the next three decades, gunite continued to be used in underground applications in many tunnels and mines across North America, although mainly in semi-structural applications (Fig. 6).

Critical to the use of shotcrete in underground support was the development of design methodologies that allowed engineers to replace conventional steel sets and timber lagging-type designs, or cast-in-place reinforced concrete lining designs with rock bolt and shotcrete designs. Preeminent among these design methodologies was the so-called New Austrian Tunneling Method (NATM), which was developed by Rabcewicz and his colleagues in Austria in the late 1950s and early 1960s (Rabcewicz 1964, 1965). This was followed by the development of the so-called Norwegian Method of Tunneling (NMT) in the 1970s (Barton et al. 1995).

In North America, dry-mix shotcrete in conjunction with rock bolts and mesh reinforcement and other types of reinforcement (for example, lattice girders and/or steel sets) was used in construction of eleven Washington, DC, subway stations during the 1970s and 1980s (Plotkin 1981). In Canada, permanent dry-mix coarse aggregate shotcrete linings with mesh reinforcement and rock bolts was used in construction of the Canadian National Railways Tunnel (the Thornton Tunnel) near the Burrard inlet in Vancouver, BC, Canada in 1968 (Mason 1968). Also, mesh-reinforced dry-mix coarse aggregate shotcrete, in conjunction with steel sets, was used in construction of reinforced linings in a subway tunnel in Toronto in 1961 (Kobler 1966). The first major use of the NATM process in Canada (although the designers referred to it as the Sequential Excavation

Method [SEM]), was construction of the underground Grandin Metro Station in soft ground in downtown Edmonton, AB, Canada (Brandt and Phelps 1989).

NEW AUSTRIAN TUNNELING METHOD (NATM)

The NATM method was primarily developed for tunneling in weak or squeezing ground. Many hundreds of different tunnels and other underground openings have been constructed using the NATM method, most of them successfully (ITA-Austria 2012), but with some notable failures (Institution of Civil Engineers 1996). Conceptually, the NATM process involves stabilizing the ground around an underground excavation in the most safe and economic manner possible by using the bearing capacity of the ground with the help of shotcrete and other support elements, together with continuous measurement of ground and lining deformations and stresses during the construction process.

The Austrian Chapter of the International Tunneling Association publication *50 Years of NATM* (ITA-Austria 2012) provides many examples worldwide of completed NATM projects. It provides a comprehensive overview of the historical development and advances in the use of the NATM process over a 50-year period. In the United Kingdom, the term "sprayed concrete lining" (SCM) is sometimes used to describe the NATM process. In North America, the term "sequential excavation method" (SEM) is sometimes used to describe the NATM process.

Barton et al. (1995) provides a useful summary of the principles of NATM design together with some examples of different NATM projects. In Scandinavia (Barton et al. 1995) and North America (Chan et al. 2002a,b), permanent shotcrete linings with high quality, low permeability, low leachability, and good durability were being produced in the 1980s for underground support in tunnels and mines using steel fiber and silica fume. These projects demonstrated that it was possible to provide high-quality, permanent, durable shotcrete linings, with shotcrete mixtures well-suited to the construction process, using either the wet- or dry-mix shotcrete processes. These findings gave rise to an interest in the concept of a single shell shotcrete lining—that is, a lining comprised of a high-quality initial shotcrete lining (with or without a waterproofing membrane) and a final (inner) reinforced permanent shotcrete lining in lieu of a cast-in-place final concrete lining.

NORWEGIAN METHOD OF TUNNELING (NMT)

Much of the tunneling work done in the Scandinavian countries has been in harder, jointed rock, which had been excavated using drill and blast methods. This excavation process often resulted in overbreak, with irregular rock surface profiles. Such excavation profiles are not well-suited for use of the NATM process (Barton et al. 1995). Prior to the 1970s, such drill and blast-excavated tunnels, where required, were supported by rock bolts and mesh covered with a plain shotcrete. These single shotcrete lining systems, while they worked reasonably well, were not optimal from either a cost or technical performance perspective. This is because of the large volumes of shotcrete required to fill the voids behind the mesh, as well as the difficulties sometimes encountered in getting good bond of the shotcrete to the rock behind the mesh and fully encapsulating the mesh. With the advent of steel FRS in the 1970s (Vandewalle 1990), and later macrosynthetic FRS (Bernard et al. 2014), these concerns could be ameliorated.

These advances were critical in the development of the Norwegian Method of Tunneling (NMT) as we know it today. The NMT is based on a quantitative (numerical) rock mass classification system (the so-called Q-System), developed by Barton and his colleagues (Barton et al. 1974; Grimstad and Barton 1993). Briefly, this design method makes recommendations for various reinforcement categories depending on rock mass classifications (rock classes varying from exceptionally good to exceptionally poor), and the underground opening span or height divided by the excavation support ratio (ESR). Papworth (2002) published a modified version of the Q-system (Fig. 7) in which recommended toughness requirements were added based on tests conducted on FRS in accordance with ASTM C1550. There were some merits in this recommendation, but more appropriately, the varying energy requirements for FRS in Joules are best included in the different envelopes. By 2005, macrosynthetic FRS was becoming widely used underground, so the modifications suggested by Papworth (2002) were applied to shotcrete reinforced with both steel and macrosynthetic fibers.

The Q-System for rock mass classification has now been used for over 40 years for assisting in selection of reinforcement systems for rock tunnels and caverns. During the past 30 years, the use of mesh reinforcement has been largely eliminated in Scandinavia and most NMT tunnel design has been based on the use of FRS reinforced with either steel

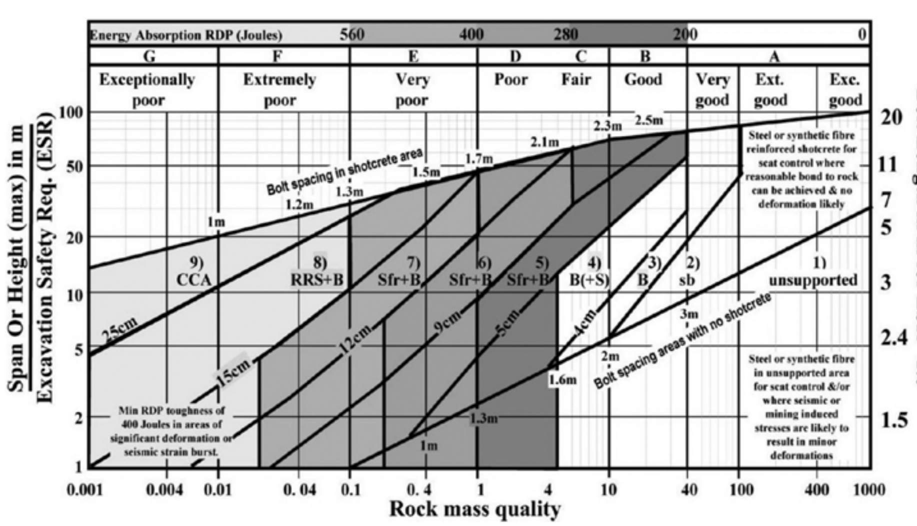

Fig. 7: Modified Barton Q-System Chart (Papworth 2002)

or macrosynthetic fibers. Many hundreds of underground structures and thousands of miles (km) of tunnels have been successfully constructed using the single-shell FRS NMT method in Scandinavia and elsewhere (Barton and Grimstad 2014). Much of the tunneling work carried out in hard rock tunnels and mines in North America since the early 1980s has also used FRS in single-shell lining systems analogous to the NMT designs.

Shotcrete in Mining

The original sand-cement gunite (dry-mix shotcrete) system developed by Carl Akeley was used, albeit with advances in shotcrete mixture designs and application equipment, in underground mines in North America and elsewhere from 1911 through to the 1950s. During this period, however, it was not the primary means of ground support and control in underground mines. Traditional ground support and control methods, such as timber and/or steel sets and timber lagging and rock bolts and screen (heavy-duty wire mesh) were the predominant methods used. Gunite was used as an auxiliary component of the support system in selected applications. During the 1950s to 1980s, most shotcrete applied in underground mines was dry-mix shotcrete applied by handheld nozzles. By the early 1980s, however, specialized shotcrete-spraying remotely controlled manipulators started to be used in mines (FIg. 8) in both aboveground and underground applications (Rispin et al. 2005).

Fig. 8: Remote control wet-mix FRS ground support in mine in North America

Fig. 9: Large underground opening for workshop in mine in Sudbury, ON, Canada, lined with macrosynthetic FRS

This acceptance was not without its challenges, as initially many miners were skeptical about the ability of a relatively thin layer of reinforced shotcrete (typically 2 to 4 in. [50 to 100 mm] thick) to support the ground in challenging mining environments with high ground stresses and deformations and seismic (rock-burst) conditions. They were used to observing problem areas in the mines by the "loose" (fallen chunks of rock) found hanging in the overhead screen and many looked at shotcrete as hiding potential problem areas. It took many training sessions and seminars and case history examples to demonstrate the theory of how shotcrete worked to provide ground control and how it helped in locating problem areas by identifying visible cracks in the shotcrete when there was significant ground movement (Larsen et al. 2009). Ground support strengthening could then be installed in areas where the shotcrete displayed significant cracking. Thompson et al. (2009) provided a useful overview of how cracks develop in shotcrete in rock under high stress and dynamic conditions and what constitutes significant cracking that would give rise to the need for remedial works.

By the 1990s, wet-mix robotically applied shotcrete was enjoying widespread use in many of the world's large mechanized underground mines (Fig. 9). Larsen et al. (2009) reported that in the 2000s, the Vale Inco Frood and Stobie underground mines used between 7800 and 10,500 yd^3 (6000 and 8000 m^3) per year of robotically applied wet-mix FRS. In Australia, since 2000, approximately 650,000 yd^3 (500,000 m^3) of wet-mix FRS (initially steel fiber-reinforced but now almost all macrosynthetic fiber-reinforced) are applied annually in metalliferous mines (Bernard et al. 2014). Macro-synthetic FRS is also developing as an essential component of ground support and methane gas control in underground coal mines, replacing the previous reliance on mesh and stone flour.

Summary

Shotcrete has come a long way since it was first developed by Carl Akeley in 1907. Modern underground support systems in tunnels such as NATM and NMT would not be possible without the use of shotcrete. Also, there are many underground mines around the world that would not exist were it not for the use of shotcrete to support underground openings during the mining cycle.

Acknowledgments

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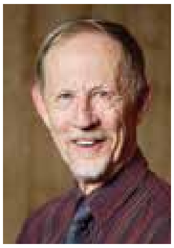

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Shotcrete Research and Development at Laval University

By Marc Jolin

The last 25 years have seen many exciting innovations in the field of shotcrete, primarily involving improved equipment, novel mixture designs, and new concrete chemical admixtures. The use of dry-mix shotcrete for ground support in mining has increased exponentially, and applications of wet-mix shotcrete have expanded to include tunnels, ground support, new structures, rehabilitation, and more. This success can be directly attributed to these innovations—through the quality of the shotcrete produced, the increased robustness and flexibility of the methods, and the greater variety of applications currently possible. Of course, all this has generated heightened expectations and increasingly stringent requirements for shotcrete in terms of durability, quality control, and mixture design characteristics.

It is well known that quality shotcrete requires a combination of adequate airflow velocity, proper material proportions, and appropriate nozzle handling. On top of all the basic concrete technology notions, high-velocity pneumatic application of concrete brings about new concerns: material losses through rebound or fallouts; buildup thickness; and compaction and encapsulation of reinforcement. Many factors related to the shooting parameters (such as process, air velocity, shooting angle, orientation, and thickness of shooting) and mixture design parameters (including cement content, silica fume content, water content, and aggregate gradation) impact shotcrete placement—all of which are simply research topics waiting to be explored.

Since 1997, the Shotcrete Laboratory at Laval University has been actively involved in education and research and development in shotcrete. This article presents a small sample of the key results and applications emerging from these research efforts on both dry- and wet-mix shotcretes to illustrate the importance given to the placement process in our research.

WET-MIX SHOTCRETE

The placement of high-strength wet-mix shotcrete is sometimes complicated by the compromise required between pumpability and shootability. At the pump, a relatively fluid, easily pumped concrete is required, whereas at the nozzle, a stiff material that neither sags nor sloughs when shot on the wall is desired. A solution to tackle this apparent paradox was put forward by Denis Beaupré in the course of his research work at the University of British Columbia,[1] and is often called the Temporary High Initial Air Content.[2] The approach is simple and very clever, whereby fresh concrete's fluidity is increased to meet pumpability requirements by introducing large amounts of entrained air bubbles instead of relying solely on water reducers and plasticizers (10 to 15% air content prior to pumping). The beauty of it is that during shooting, large amounts of air are lost upon impact and compaction; reduced workability is instantaneously obtained as shotcrete hits the receiving surface, thus improving the shootability of the shotcrete. Air loss upon impact is known as the "slump killing" effect.

Although this concept has seen many early users in the industry and is now used around the globe, it was only later that a clear understanding of the mechanisms behind the improved pumpability was brought to light by Jolin et al.[3] When trying to understand exactly what happens in the delivery hoses, Jolin et al. found that all the air bubbles were easily dissolved into the cement paste under the normal operating pressures found in concrete pumping. Through pumping a dozen different wet-mix concretes, it was found that the capacity to pump or not had apparently little to do with the mixture design (Table 1). Indeed, only small modification of the total paste content for a given mixture design would make it pumpable. Considering that the relative proportion of aggregates and the water-binder (*w/b*) ratio were both maintained constant, it is difficult, looking at the first columns of Table 1, to understand the key parameters that made a mixture pumpable or not. (Note: all mixtures would pump in a 2 in. [50 mm] internal diameter hose; the challenge in this study was going down to a smaller 1.5 in. [38 mm] internal diameter hose.)

A careful examination of the results reported in Table 1, as well as a comprehensive analysis of the laboratory observation and available literature, led the authors to derive what is called the Real Paste Content (last column of Table 1, complete calculation method in Jolin et al.[3]), defined as the "amount of paste (%) present in the concrete while under pressure." Therefore, it is a volumetric interpretation of the paste content when the material is under pressure.

Table 1: Experimental results of pumpability test

Mixture*	Binder content lb/yd³ (kg/m³)	Air content (before pumping), %	Pumpability	Real paste content†
A	661 (392)	13	NO	33.2
A-*mod1*	683 (405)	13	*Blocked-2 strokes*	34.2
A-*mod2*	700 (415)	13	Pumpable	35.1
B	684 (406)	7	NO	31.8
B-*mod*	750 (445)	7	Pumpable	35.1
C	738 (438)	3	NO	33.1
C-*mod*	784 (465)	3	Pumpable	35.1
C	679 (403)	13	NO	33.8
C-*mod*	708 (420)	13	Pumpable	35.2
D	674 (400)	13	NO	33.8
D-*mod*	700 (415)	13	Pumpable	35.1

*All water-binder ratios are 0.41; slump for all mixtures is 75 to 100 mm (3 to 4 in.)
†Volume of paste in the concrete under pressure

It is interesting to note that the paste volume changes as pressure is applied to the concrete because the dissolving air volume diminishes to negligible values. Therefore, as pressure increases, the paste content becomes equivalent to the volume of binder material and water.

As it can be seen, it appears that a value of real paste content of 35.1% is somewhat a minimum value below which a mixture is not pumpable (with the particular aggregates used and a 1.5 in. [38 mm] internal diameter hose). The implications of this finding are significant; it not only shows (again) the importance of providing a sufficient amount of paste to coat all the aggregates and lubricate the inner wall of the delivery hoses, but it more interestingly demonstrates that there is a threshold value for the real paste content below which pumping is impossible. Combined with previous research, we can further affirm that this threshold value will change with the aggregate gradation and the hose diameter.[4,5] The real paste content calculated by Jolin et al. is the first time we have an actual value and a calculation method to start optimizing our mixture design for pumping and better select our aggregates size and proportions.

SERVICE LIFE PREDICTION

Service life prediction is one of the most recent and important topics considered in the Shotcrete Laboratory at Laval University. The service life modeling tool called STADIUM® was adopted both for its capacity to accept varying types of concrete and its capability to include numerous types of transport mechanisms in modeling the concrete's performance.[6] Service life modeling is an invaluable tool for owners and engineers, as it considers the transport mechanisms of deleterious substances in the concrete porous network based on exposure conditions. The driving force behind each mechanism is quite straight forward: pressure, relative humidity and concentration gradient, and capillary suction. They can all act at the same time (in the same direction, independently, or even one against another) when considering contaminant ingress into concrete (for example, ingress of salt water and oxygen to initiate corrosion in a tidal zone for a concrete column). By considering time-dependent environmental conditions and transport properties, a service life modeling tool provides realistic estimates of the progression of concrete degradation and reinforcing steel corrosion. Thus, it can yield much more information on durability than possible with more conventional tests such as the measurement of porosity (ASTM C642) or of chloride penetration (ASTM C1202 or C1543).

Using the STADIUM simulation tool in the case study of a concrete dry-dock exposed to seawater, it was found that all the shotcrete tested was predicted to have better durability than an equivalent cast-in-place concrete. The most important conclusion to be drawn (Bolduc et al.[7]) is that the high-velocity pneumatic placement process that defines sprayed concrete plays a significant and positive role on the quality of the in-place concrete. Recent rather comprehensive research projects by Zhang et al.[8] as well as another from Power[9] support this statement; similar concrete mixtures always behaved better in the long term when they are sprayed as opposed to being cast-in-place.

SHOTCRETE PLACEMENT—ENCAPSULATION QUALITY

Proper reinforcement encapsulation is a concern among structural engineers, as there are limited specific guidelines for designers using shotcrete. Imperfections behind reinforcing bars (or any other obstacles) are reported in cases of excessive use of set-accelerating admixtures or with unskilled nozzlemen. To evaluate these concerns, past research has mainly focused on optimal mixture consistencies and best nozzle handling techniques to obtain perfect encapsulation.[10,11] Although these approaches have limited the creation of imperfections behind reinforcement by improving the rheology of the mixtures, the main issue has remained unresolved for decades: what is the influence of the size and distribution of voids on structural performance?

Unfortunately, the reliability and applicability of various encapsulation quality evaluation systems has been subject to ongoing debate from industry experts who have emphasized that evaluating the impact of a void's size on the bond strength of bars to concrete would be more useful. Early studies confirmed the assumption that small scattered voids would not have a considerable negative effect. However, a tool for the design and evaluation of shotcrete structures had yet to be offered. Thus, an extensive experimental investigation in which complex bond test specimens were built with different qualities of reinforcing bar encapsulation was undertaken to determine the impact of void geometry on bond performance of the bars by evaluating the slope of the load-slip curve, ultimate load, and failure mode. Part of the research created artificial voids encased with a cast-in-place shotcrete mixture to precisely establish their geometry and location.

Preliminary results have confirmed that a void with an unbonded perimeter of approximately 20% (refer to Fig. 1) of the bar's perimeter sets the limit at which bond strength begins to decrease drastically as initially hinted in a previous study.[12] Beyond that 20% unbonded perimeter limit, a change from a splitting failure mode to a pullout mode seems to be favored. Comparing sprayed and cast-in-place specimens, it was found that the slope of the load-slip curve was always stiffer for shotcreted specimens when the optimal airflow velocity was used. Further analyses will help engineers reliably assess the bond strength of reinforcing bars by the visual examination of cores and determine if corrective design measures are required.

Fig. 1: 20% unbonded perimeter (artificial void)

SHOTCRETE PLACEMENT—SPRAY

Further development of knowledge on shotcrete greatly depends on our comprehension of the material placement process, particularly for the reduction of rebound and control of the in-place material compaction and composition. Despite considerable advances in concrete mixture design for shotcreting in past decades, many aspects of the placement process are still not clearly understood.

Most of our understanding on the rebound phenomenon today relies on the work of Armelin and Banthia,[13,14] who were successful in modeling the different impact phases for a single aggregate on a fresh concrete substrate. Their work has allowed for demonstrating the key role of the energy (mass and velocity) of the incoming particles on the amount of rebound. Further investigation of the placement process was required—from the concrete transport in the hose and the shotcrete spraying at the nozzle to the study of the material impact on the surface. This reflection led to the development of a novel research approach using a high-speed camera, a project led by Ginouse (and Jolin) during his thesis.[15,16] Amongst the numerous innovative testing methods and significant results presented in his work, two of the most interesting ones can be seen in Fig. 2 and 3.

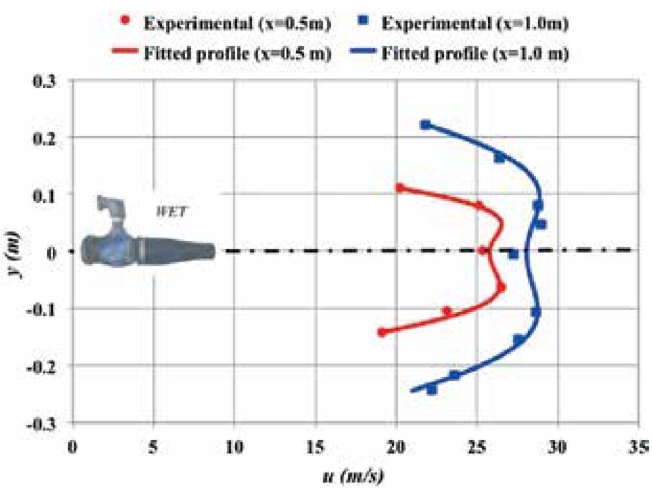

Fig. 2: Experimental and fitted velocity profiles u(y) obtained at 1.6 and 3.3 ft (0.5 and 1.0 m) from the wet-mix nozzle outlet

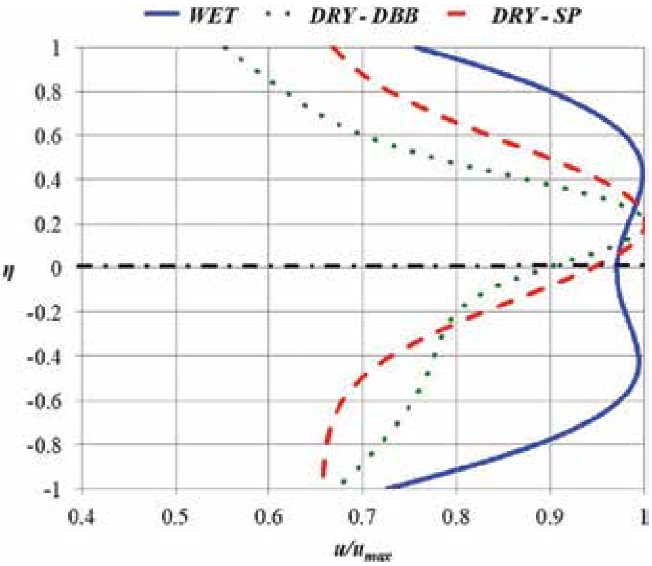

Fig. 3: Normalized axial velocity profiles obtained for the three shotcrete nozzles considered

In Fig. 2, the material velocity of a wet-mix shotcrete spray is followed as it exits the nozzle and values are reported for two positions: at 1.6 and 3.3 ft (0.5 and 1.0 m) for the exit of the nozzle. Obviously, the spray pattern widens as the distance from the nozzle increases, but what is noteworthy is the fact that the material accelerates between the 1.6 and the 3.3 ft (0.5 and 1.0 m) markers. In other words, the effect of the compressed air added at the nozzle has an important role even outside the nozzle as it keeps pushing the material forward.

Figure 3 reports the velocity profiles obtained 3.3 ft (1.0 m) for three different nozzles (one wet and two dry). For comparison purposes, the profiles have been normalized. What stands out in Fig. 3 is the differences in the shape of the profiles between dry- and wet-mix nozzles. With the wet-mix, the shape suggests that most of the particles travel at similar velocities, whereas the dry-mix nozzles show a rapid decrease of velocity as we move away from the middle of the spray axis. Keeping in mind the importance of the velocity (energy) of the particles as they hit the surface for control of rebound, the curves in Fig. 3 somewhat intuitively explain the higher amount of rebound found in dry-mix shotcrete where a smaller number of particles are traveling at the right velocity to minimize rebound when compared to wet-mix.

These two figures are only a small example of what this study allowed us to do. Further advances have since taken place: different wet-mix nozzle designs were compared to identify key parameters controlling velocity and rebound, and improved nozzle designs for dry-mix have been explored to better control the velocity profiles.

Conclusions

This article offers a brief glimpse of a large amount of information available in what can be a complex field. The author hopes that some of the information provided in this paper will support and promote more projects involving the use of shotcrete over conventional concrete. Such projects will only be feasible if the material (concrete) and placement method (spraying) are well understood by the specifier, designer, and contractor. Mistakes can be avoided by increasing the robustness of key components of the process and by adequately training crews, especially the nozzlemen who perform the job.

Acknowledgments

An article like this one would not be complete without acknowledging the contribution, through great efforts and hard work, of numerous students to these and many other projects. If you have ever held a nozzle in your hand or shoveled rebound, you know what it's like, and they all have! You can appreciate their level of dedication in conducting research projects in this field using full-scale equipment. I am indebted to all of them and they have my gratitude.

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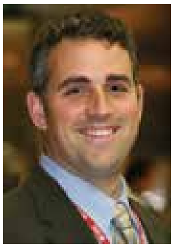

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The History of Shotcrete Equipment

Dry-Mix Shotcrete—The First Shotcrete

By Patrick Bridger

Most of you have heard that Carl E. Akeley was credited with the invention of the first successful shotcrete machine. Akeley was employed by the Field Museum of Natural History in Chicago, IL, where, in his studio, he continued to study anatomy so that the animal skins would fit his models correctly. It was at this point in his career when he developed his most successful inventions, including improvements to the motion picture camera as well as the development of the cement gun. A common belief is that Akeley developed the cement gun to rapidly and economically build up forms by spraying cement grout onto a frame so that animal skins could be placed and stretched for his displays (Fig. 1).

This theory has never been proven, as there is no clear evidence of this being the case. A more likely scenario comes from a different story by Clarence Dewey, Akeley's assistant. In 1907, Dewey's account was that the Field Museum building was in dire need of repair and funds were limited for such aesthetic repairs. Dewey had been working with a compressed air machine, painting imitation rocks for an Akeley exhibit, when the museum director asked Dewey and Akeley if they could build a machine to spray plaster as an effective means of repairing the exterior of the building. The moment of intuition is related by Akeley in his memoirs:

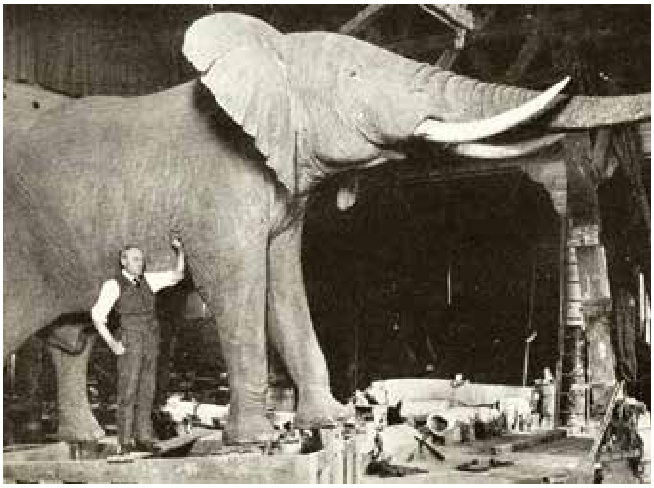


Fig. 1: Charles Akeley at Field Museum of Natural History in Chicago

"In the many experiments of one kind and another that I had tried in working out methods for mannequin making, I had among other things used a compressed air machine. It occurred to me that it would be possible to make an apparatus on this principal that would spray a very liquid concrete on to the side of a building."

Akeley realized that he did not have the expertise or finances to market the machine successfully. After approximately 3 years of attempting to generate public interest, he successfully succeeded in finding several backers. In 1911, they incorporated the General Cement Gun Product Company to manufacture the gun, and General Cement Gun Company to market the machine. Those owning stock in the General Cement Gun Company were John E. Shepherd, Robert L. McElroy, Carl E. Akeley, Charles A. Cooper, Garret D. Cooper, Wallace B. Wolf, and Worth E. Caylor. To protect the investment from possible infringement suits, they purchased the following patents: a sandblaster apparatus (773,665, and 783,218) invented by John D. Murray, and sandblaster nozzle (839,483) invented by William H. Kelly. The similarities between the Murray sandblaster and the Akeley cement gun are undeniable. Both handle a dry mixture in the hopper, both use a single hopper, and most importantly, in both, hydration occurs in the nozzle. The second Akeley patent reveals a dual-chamber machine, which allows the upper chamber to be refilled while the lower chamber is in use, thus allowing the machine to be kept in continuous use. In the prototype, the feed wheel was in a vertical position, while the second patent placed the feed wheel in the horizontal position for improved material control and to prevent clogging. The feed wheel was the most important technological development other than the nozzle. When the cement was mixed with the moist sand, the horizontal feed wheel breaks up the mixture before introducing the material into the hose. Without the feed wheel, it would be difficult to control the mixture and arrive at proper results.[1]

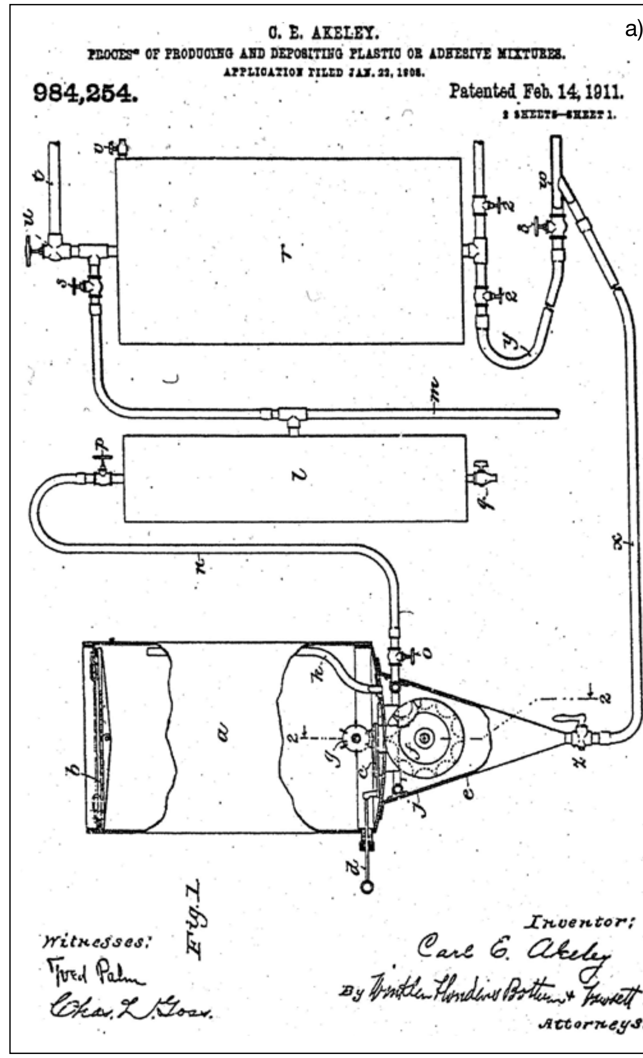
Akeley's patent (984,254) (Fig. 2(a) and (b)) relates an important discovery well:

"Hydraulic cement is more efficient as a binding agent when it is permitted to set shortly after hydration and without physical disturbance, in a position where it is intended to permanently remain. In the former process of making a

concrete, the utilization of this law was impossible from the nature of its performance, as the cement was hydrated and mechanically mixed with sand or similar material, and when mixed, the conglomerate was taken to the place of application and applied, the result being that the crystalline form of the hydrated cement was necessarily broken and hence made less effective as a binding agent. Another law is that hydraulic cement is more effective when hydration is accomplished with just the amount of water needed to supply the water of crystallization and that under proper conditions such cement will take up the exact amount of water or moisture needed for this purpose. In the operation of the former process, such conditions were impossible in the nature of the performance.*

"In the operation of my process, I bring the dry cement and sand, either separately or mixed, together in the appropriate proportions to the point of delivery adjacent to the point of application. Through a separate conveyor I bring the water to the same point, and under pressure I forcibly project the three elements together against the object or structure. In carrying out my process, I prefer to unite the three elements, sand, cement, and water, in a suitable nozzle from which they are together forcibly projected against the object. I have observed that the point at which I bring about in the projecting of these elements with the cement sand and water together in the manner indicated, permit the cement to take up just enough water or moisture to effectively bring about its crystallization. The particles of cement, having taken up just the right amount of water, are violently projected against the object where they are intended to remain and set, thus these particles are immediately placed upon hydration in position where they are to remain. They are not again disturbed, and in view of the fact that they have taken upon only the sufficient water for the purpose of their hydration, they rapidly crystallize and set. The fact that the sand is also brought in contact with the water, (predampened material) wets it sufficiently to be united with cement. In other words, the individual particles of sand are moistened and consequently in a better condition to cooperate with cement forming the concrete. Furthermore, the fact that all of these elements are violently projected against the object continuously and forcibly operates to drive the particles home into the interstices of the surface presented, thus tamping the concrete as it is formed and expelling surplus water or included air that may be present, leaving the concrete hard, dense, and homogeneous."

On May 9, 1911, Patent 991,814 was issued for an "Apparatus for



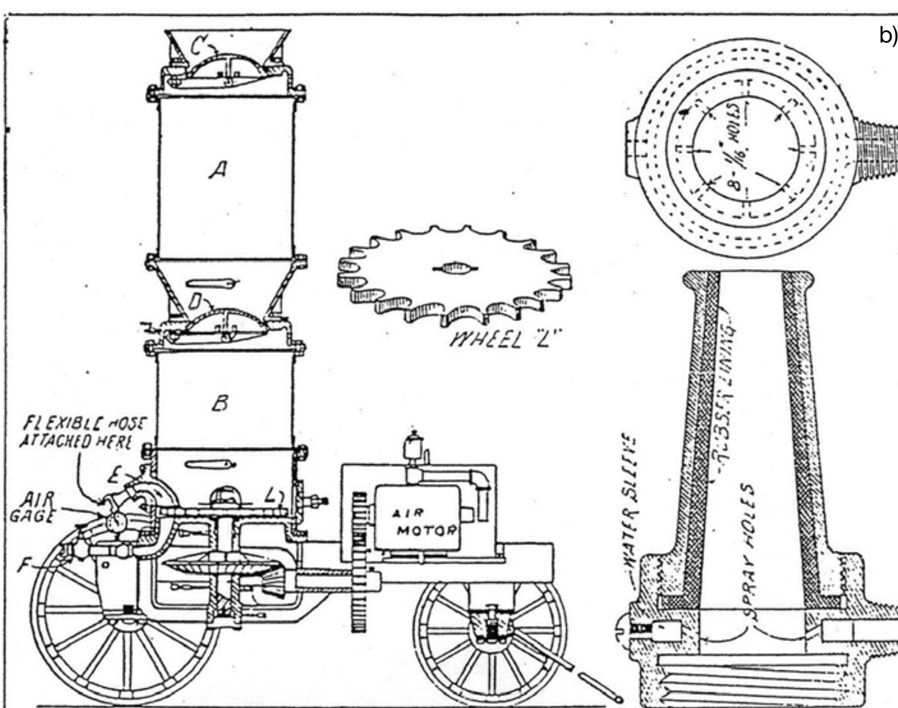


Fig. 2(a) and (b): Original drawings from Patent No. 984254 mixing and applying plastic or adhesive materials." Although Akeley's name was on the patent, is seems that others were busier in promoting the invention than he was. In December 1910, the cement gun was already exhibited at the Cement Show in New York's Madison Square Garden. At the 7th Annual Convention of the National Association of Cement Users held during the show, a paper delivered by G.L. Prentiss, Vice President of Parsons Manufacturing Company, NY, about the cement gun and its use, particularly in lining the Hunters Brook Siphon of the New York Water Supply at Yorkshire Heights, impressed the audience just as much as the machine itself. A civil engineer named S.W. Traylor was especially quick to appreciate the wide variety of uses for the cement gun. His engineering company in Allentown, PA, acquired the rights to the machine, and he soon renamed the firm the "Cement Gun Company."

The term "gunite" was coined in 1912, and the unique idea of applying cement mortar onto a surface at high velocity was an immediate success. Early projects included encasement of structural steel support elements of New York's Grand Central Station to strengthen and protect them against fire and corrosion. The density, bond characteristics, and compatibility with structural steel elements, as well as the longevity of protection, created a design and construction demand for this type of application throughout the rail and bridge industries. Water transportation and storage facilities became common gunite construction applications because of the reduced forming requirements and the superior properties of concrete placed by the pneumatic spray method.[2]

From 1911 to 1916, development of the machine and nozzles continued to progress. The original model was the model G.L. machine, but the model N-0 was soon introduced in 1914. The model N-0 was still a double-chamber machine, but the vessel geometry changed to the hourglass shape that is most recognized in Fig. 3 and 4.

The Cement Gun Company had a contracting department, but they did allow sales of machines to anyone, as shown in Fig. 5.

The cement gun was widely used in building construction, strengthening, façade repair, corrosion protection, fireproofing, furnace lining (refractory), mining, tunneling, canal lining, slope stabilization, water and wastewater tanks, and various other applications, as we still use shotcrete today. These machines were sold throughout the United States and spread to many other countries throughout the world in relatively little time once they were commercially available. (I have in my possession the original "Birth Certificate" book, which is a handwritten recording of every customer who purchased a cement gun from 1914 until the early 1970s.)

It wasn't until after WWII that technological advances were made in the continuing development of shotcrete machines. Sometime in the late 1940s, a company from Troy, MI, called NFS Industries developed the first rotary barrel type device called the "Jetcreter." Essentially, this is a rotary lock air chamber device in which the vertical rotor cylinders are continuously fed by gravity and discharged straight down to the outlet below. This proved to be a successful machine and enabled higher output for various applications. In addition to the development of the rotor machine, they also developed a highly successful volumetric continuous mixer for site mixing and feeding the rotor machine.

Hans Egger, from Meynadier AG of Switzerland, took notice of this machine and made it more compact for use in tunnel construction. In 1957, the Meyco GM-57 was introduced and soon became a popular machine in tunnel construction and other higher-output applications. Further improvements were made to the design of the clamping device within the next decade, and a smaller version called a GM-27 was introduced. Aliva is another company that further made design changes and improvements of the rotary barrel gun,

Fig. 3

Fig. 4: Model N-2, circa 1916

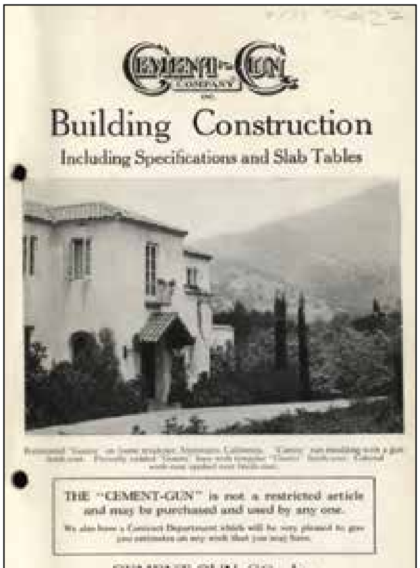


Fig. 5: Cement-Gun Company Bulletin

Fig. 6: Meyco GM-060 Rotary Machine

Fig. 7: Aliva AL-252 Rotary Machine

Fig. 8: Reed Model LOVA

which Sika acquired, further improved, and very successfully marketed worldwide in underground construction.

Today, both Meyco and Aliva brand rotary machines (refer to Fig. 6 and 7) are alive and well and available worldwide. Aliva is recognized worldwide in mining and tunneling construction as well as refractory use. The current Meyco versions are available from Normet, who acquired the Meyco dry-mix shotcrete machines within the last 5 years. There are copies of both the Aliva and Meyco brand machines, but none compare to the robustness of the original, genuine versions of the Swiss-designed and built machines.

The next dry-mix shotcrete machine development came in the 1960s by Frank Reed with the development of the rotary bowl-type shotcrete machine.

The rotary transport bowl is divided into radial compartments, is gravity fed, and is pneumatically discharged into the outlet and connected delivery hose, as illustrated in Fig. 8.

The rotary bowl gun design became very successful in a wide variety of shotcrete applications and the technology was readily accepted worldwide. Like the pressure vessel and rotary barrel design, the rotary bowl machine has also been copied by various other manufacturers. The Reed models LOVA and SOVA are popular in applications such as concrete repair, refractory, new construction, swimming pools, tunneling, mining, and various other applications.

Fig. 9: Frank Reed

Although never commercially produced, Frank Reed (Fig. 9) also patented an automatic double-chamber pressure vessel machine. Frank was quite the innovator in dry-mix shotcrete equipment.

J. F. Shea Construction used the Reed machines in the 1960s for their tunnel construction projects. Shea purchased Reed in 1970.

Once all three successful types of dry-mix shotcrete machines were established, not much changed in the technological development of dry-mix shotcrete equipment. The Cement Gun Company operated continuously from 1911 under the ownership of the Collier & Roberts family of three generations with other names of Allentown Pneumatic Gun and Allentown Pump & Gun. In 1991, Master Builders Inc. acquired Allentown and divested the company in 2004 to private ownership, which George Yoggy and myself were investors. Putzmeister acquired Allentown Equipment in 2007 and eventually closed operations down in Allentown in 2011 and moved the company to Putzmeister headquarters in Sturtevant, WI. In 2012, Putzmeister eliminated the Allentown brand and kept production of the Allentown shotcrete products under the Putzmeister brand.

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1. Rodriguez, L., *From Elephants to Swimming Pools, Carl Akeley, Samuel W. Traylor and the Development of the Cement Gun*, Canal History and Technology Press, Easton, PA, 2006, 150 pp.

2. Yoggy, G. D., "The History of Shotcrete," *Shotcrete*, V. 7, No. 3, Summer 2005, pp. 26-32.

Patrick Bridger *is the General Manager at King Shotcrete Equipment Inc. He has 33 years in the industry, with the past 3 years at King. Bridger began his career at Shotcrete Plus in San Antonio, TX, under the leadership and mentorship of George Yoggy. He spent 10 years working as a refractory shotcrete contractor in Texas, and then 17 years in a senior management role with Allentown/Putzmeister America. Bridger is a Past President of ASA and has been an active member since its inception in 1998.*

The History of Shotcrete Equipment—Wet Mix

Part I: Aussie Innovation with S-Tube Shotcrete Pumps

By Ian Hay

In Australia, when concrete swimming pools started becoming popular with the average home owner in the late 1950s and early 1960s, the pools were typically sprayed with dry-mix shotcrete (gunite). However, we recognized that using premixed concrete with a form of shotcrete gun may have many benefits. The first attempts used a hopper with a rotating chain belt at the bottom, much like a dry-gun rotor but with 3 in. (75 mm) washers spaced at 4 in. (100 mm) with the chain in the center of the washer to form a material cavity. It ran in a 3 in. (75 mm) rubber tube and had a 600 ft^3/min (17 m^3/min) air compressor that blew the wet mix out of the cavity and up the delivery line. They were dusty, noisy, huge, and unreliable.

Later in the early 1960s, imported "squeezecrete" pumps were used to shotcrete pools. These were much cleaner and could have the wet-mix concrete delivered in a transit mixer. However, the distance from curbside concrete delivery through the hose to placing in the pool was a restriction, as the squeeze tubes could not withstand high pressure.

I had always lived on the Northern beaches and the Brookvale industrial area was where the concrete ready mix industry started with Pioneer Concrete, which ended up being a global company (now Hansin). So, I was hanging around the area and, being young, could just walk in to these outfits. The Fowler Wood factory made transit mixers and there were three ready mix plants close together. When I started to build the first Transcrete pump, I used the "bullet" valve system. There were dozens of small engineering and machine shops that made parts for Fowler Wood so it was easy to get parts made. Pioneer even supplied the paint and yard space to spray our first pump (they did not give a toss if it had to be "Pioneer Green & White"). All three plants provided assistance in developing pumpable concrete mixtures. Their concrete mixture design engineers were only too eager to give me the "secrets" of mixture designs.

Once we had a concrete pump, we sold 36 pumps in the first full year of production. We were approached by swimming pool sprayers wanting to ditch the squeezecrete pumps. We tried the "bullet valves" and while they worked when in perfect condition, once they had excessive wear, they were a waste of time.

In 1974, we received an order for several new pumps from a New Zealand equipment dealer. At the time, the only way you could import a concrete pump to New Zealand (NZ) was to apply for an import license, and it was rare that one would be issued. The NZ dealer told us that he had such a license, but as it turns out, he was only hoping to get approval. Now with $50,000 of finished pumps and a severe recession, I jumped in a plane and tried to convince the NZ Customs Department to issue a license. No such luck. However, as I was in NZ, I made several calls to local concrete pumping operations. It was obvious that Transcrete pumps, 60 to 90 yd^3/h (45 to 70 m^3/h) were way too big for the NZ market and what they needed was a much smaller 30 yd^3/h (25 m^3/h) pump, trailer-mounted and suitable for masonry block filling ("3/8 in. [10 mm] piss and pebbles.")

The NZ pumpers were using a lot of Mayco C30HD mechanical ball valve pumps. There was no way bullet valve pumps would work, with the smaller the output and being more costly to operate due to wear.

I jumped on a plane back to Australia and on the flight back came up with the S-tube idea. We had the first unit built in 2 weeks and the first Mark 1 pump sold.

To get over the NZ license problem, the importer suggested we build in NZ and send back to Australia as well as export to Southeast Asia, as we had entered the Asian market in 1974. I ended up with a factory full of finished concrete pumps, a recession, and creditors snapping at my heels. So, I put all the finished pumps in boats to Hong Kong, Singapore, Malaysia, and the Philippines. At least I was in control of disposal at full value.

After 1 year, we were back in a strong financial position and ready to start producing S-tube trailer pumps. The NZ venture was a failure quality-wise, so we manufactured in Australia. However, the S-tube pump was too small for Australian pumpers and not suitable for Asian concrete mixtures. I had made several trips to Los Angeles, CA, in 1974 with the view of selling our bullet pumps. Unfortunately, the market in the United States was also in a recession, but I established some good contacts and passed out S-tube brochures to people using Mayco C30HD ball valve pumps. At that time, the market primarily consisted of ball valve trailer pumps or truck-mounted boom pumps. Whiteman had a small 30 yd^3 (25 m^3) pump but it was a sliding gate valve design and never took off.

Why the United States? Here I was sitting on a large bank balance, no local sales; the Southeast Asia market was 20% of sales and 80% of the problems. Considering the cost of transport, hotels, language, and other factors, I realized that the United States was the place to be. The Mayco ball valve pumps were having problems pumping structural pea gravel concrete mixtures due to a cement shortage. The S-tube pumps we sold in Australia were handling low-slump 0.75 in. (19 mm) pea gravel mixtures and pumped fast enough for normal home foundations.

We had also started selling S-tube pumps to the swimming pool industry with great success both in performance and reliability. I spoke to a customer who had replaced his squeezecrete rigs with Transcrete S-tube models and asked him how they compared with his old pumps. His reply: “The only thing I miss is the monthly invoice for replacement tubes.”

At that time, we were selling the trailer-mounted S-tube pump for A$ 20,000.00 (US$ 16,000.00), each factory direct with no dealers.

Jumpstarting the United States Market

I had given out S-tube trailer pump brochures to several contacts in the United States and the details included the phone number of my in-laws living in La Mirada, CA. My office phone rang on a Saturday morning and it was my mother-in-law, saying some guy wanted to contact me, and that he wanted to buy a concrete pump. I phoned the number given and low and behold it was Fran Wilson, who was working as a design consultant with Allentown. Fran and I had been corresponding for years and unbeknownst to me at the time, he was designing a small S-tube pump for Mayco. Fran was using my information and selling the ideas to Mayco.

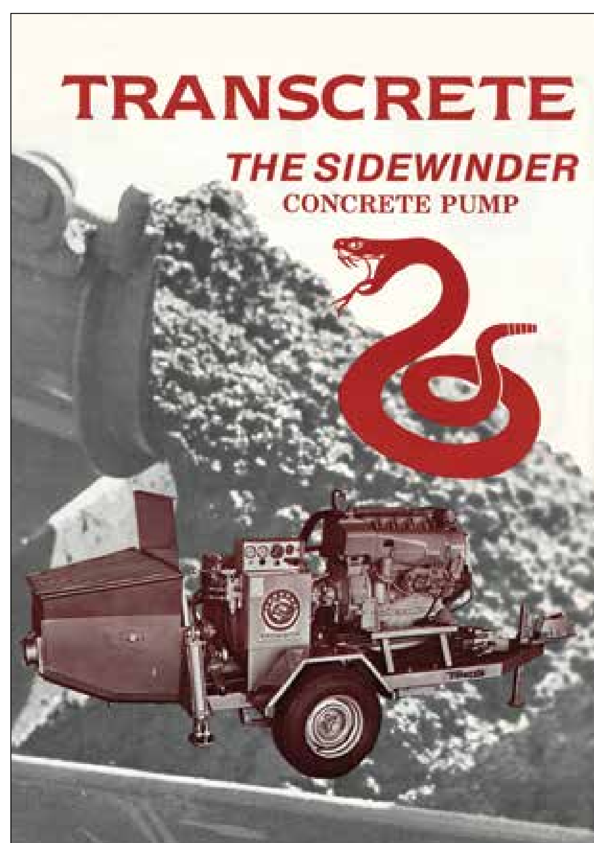
Fran had received a call from Joe Cerretini, a pumper based in Binghamton, NY, who wanted to buy a 30 yd^3 (25 m^3) trailer pump. Fran gave me Joe’s phone number and I called him straight away. We spoke for quite a while and I suggested that if he was keen and had the money to buy a pump, I would bring a pump over to New York and give him a demo, provided he paid up if it does what I told him it would do.

By this time, I had made up my mind that we were going to sell into the United States and called the pump a “Sidewinder.” We were already air freighting pumps into Southeast Asia because we didn’t want our investment going on a “3-week cruise.” We also discovered an airline tariff concession for “mining” equipment.

So, I put a new Sidewinder on a plane to New York and followed it on a separate flight. There was drama using a Greek airline from Australia that offloaded the pump in Europe and then an Irish airline from Europe to New York… but that’s another story.

First Use and Expansion in the United States

Fran had advised Bill Roberts at Allentown about the Sidewinder demo at a site in Syracuse, NY. So, on the day of the demo, we had Fran, Bill Roberts (President), and Earoll Roebuck (VP, Marketing) from Allentown, plus their design



engineer in attendance. The demo was a great success and Joe paid me in full for the pump. Bill Roberts immediately invited me to the Allentown factory, as he was keen to be the Sidewinder importer.

The Allentown facility was great as far as real estate goes, but there was not much going on as far as manufacturing. I could see that they were way behind on the technical side. Bill presented a proposal whereby Transcrete would ship Allentown Sidewinder pumps, fewer diesel engines, and a few other components. His reason was: Why import a diesel engine from Europe to Australia, then fit it and ship to the United States? Why not just buy the diesel engine in the United States and fit it in the Allentown factory? I replied, “Bill, don’t complicate things…you buy a complete pump at a fixed price delivered to your factory loading dock.” Why mess with extra time and effort and not save any money? We are buying diesel engines at far less than you can buy them. Apart from his “economic logic” he wanted to call the pump “son of Pumpit” after Allentown’s large trailer pump. When I asked what number of pumps he would buy, he came back with one a month, maybe! I replied, “Bill, we are selling 20 per month in Australia alone.” It was obvious that Transcrete was a much stronger company than Allentown, so I did not conclude any business with Allentown.

Bill did meet me in Honolulu, HI, on my way back to Australia, but I was still not comfortable with him—besides, I had already done a deal with Bennett Brothers. Prior to doing the Bennett Brothers deal, I had approached Rick Horsfall, Vice President at Thomsen, with the offer to sell Thomsen our Sidewinders. Interestingly, in all the time I spent with Bill, shotcrete never came into the conversation.

SPRAYING CONCRETE! THEY JUST USE THE SIDEWINDER IN AUSTRALIA

The deal I made with Bennett Brothers was that Transcrete would provide finished pumps on consignment, with payment within 7 days from sale and paid invoice. Transcrete would provide, design, and pay all advertising costs. We agreed to send over several pumps to kick the deal off. I ended up spending several weeks with them initially. During the first week at Bennett Brothers, Dick Bennet was having a discussion with a customer having problems spraying rail culverts using a Thomsen boom pump that Dick had modified to handle shotcrete mixtures. He said to me, “What pumps do they use in Australia to spray concrete?” I replied, “Squeezecrete pumps were popular but they now use Sidewinders.” Dick came back with, “Like the Sidewinders outside?” Sure, the same.

Dick quickly organized a demo for the Sidewinder down in San Clemente. The contractor laid out over 180 ft (55 m) of 2 in. (50 mm) hose. I think he was trying to show the smartarse Aussie a thing or two. The demo was a great success and they sold two Sidewinder pumps that day. Dick had a salesman, Marion Ryder, who had been in the industry since concrete pumping started and knew pumpers all over the United States. Marion was over the moon and started calling pool builders and gunite contractors. He contacted Action Equipment in Arizona and another pool sprayer, Al Connors. Al was a large contractor in Arizona and was running Mayco C30 HD machines, one on each pool with a backup in the workshop. If one crashed on the job, they would just haul out another. The Sidewinder was diesel powered; Mayco ran on gasoline. Gas was costly and hard to get due to the price rise in the Middle East. So apart from the Sidewinder being reliable, and did not wear out fast, it provided the side benefit that the pumper could siphon diesel out of the concrete truck to run the pump.

Cheers! Part Two will complete the story in a future issue of *Shotcrete* magazine

Born in Australia in 1941, ***Ian Hay*** *has spent a lifetime in widely diverse careers, including as a butcher, selling neon and outdoor signage, concrete placement, real estate, and eventually selling the Sidewinder S-tube pump for shotcrete placement.*

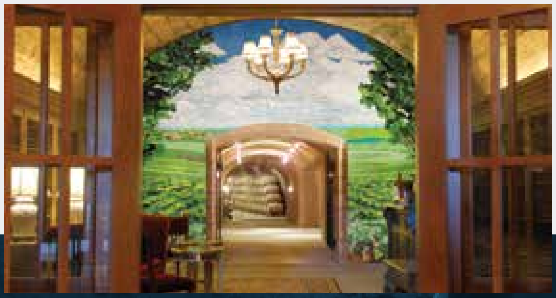
ASA Celebrates 20 Years at our FIRST ASA SHOTCRETE CONVENTION!

March 11-13, 2018 | Silverado Resort and Spa | Napa, CA

SCHEDULE AT A GLANCE

SUNDAY, MARCH 11, 2018	
6:30 am – 8:30 am	Registration
7:30 am – 9:30 am	Continental Breakfast Buffet
8:00 am – 4:00 pm	Optional ticketed events*
2:00 pm – 3:30 pm	ACI C660 – Shotcrete Nozzleman Certification Committee
3:30 pm – 5:00 pm	ACI C601-I – Shotcrete Inspector's Certification Committee
6:00 pm	Dinner on your own
MONDAY, MARCH 12, 2018	
6:30 am – 7:30 am	Registration
6:30 am – 8:00 am	Continental Breakfast Buffet
8:00 am – 5:00 pm	Committee meetings† (lunch included)
8:00 am – 5:00 pm	Optional ticketed events*
6:00 pm – 9:00 pm	Informal Golf Awards/Committee Dinner*
TUESDAY, MARCH 13, 2018	
6:30 am – 7:30 am	Registration
6:30 am – 8:00 am	Continental Breakfast Buffet
8:00 am – 12:00 pm	Shotcrete Technology Presentations‡ (3 tracks)
10:00 am – 11:30 pm	Optional ticketed event*
12:00 pm – 1:00 pm	Buffet Lunch
1:00 pm – 3:00 pm	Shotcrete Technology Presentations‡ (3 tracks)
5:00 pm – 5:20 pm	Bus departures to Inglenook Winery
6:00 pm – 10:00 pm	Outstanding Shotcrete Project Awards Banquet*
WEDNESDAY, MARCH 14, 2018	
7:00 am – 9:00 am	Continental Breakfast Buffet
11:00 am	Checkout

*See Optional Ticketed Events for details
†See Committee Meetings for detailed schedule
‡See Shotcrete Technology Conference for speakers and topics



www.shotcrete.org/20thAnniversary

SHOTCRETE CONVENTION & TECHNOLOGY CONFERENCE

COMMITTEE MEETINGS

Monday, March 12, 2018

Times	Room A	Room B
8:00 am – 9:00 am	Education	Underground
9:00 am – 10:00 am	Membership	Pool & Recreational
10:00 am – 10:30 am	Break	
10:30 am – 11:30 am	Marketing	Safety
11:30 am – 12:00 pm	Publications	—
12:00 pm – 1:00 pm	Lunch	—
1:00 pm – 2:00 pm	Contractor Qualifications	—
2:00 pm – 2:30 pm	Break	—
2:30 pm – 5:00 pm	Board of Direction	—

SPONSORS & EXHIBITORS

Sponsorship for the Convention provides exceptional promotional opportunities at the Convention and Banquet venues, ASA's Booth at World of Concrete, on the ASA website, in *Shotcrete* magazine, and on social media forums! Additionally, Gold Sponsors can secure a tabletop exhibit at the Convention on a first-come, first-served basis with their sponsorship. The exhibit hall will be located where breaks and convention meals take place and are open throughout the event. Convention attendees will have repeated opportunities to meet with you and network in a comfortable setting with grand garden views! Two Sponsorship Levels available: Gold: $2500 and Silver: $1000. See full Prospectus for details and visit **www.shotcrete.org/sponsorship**.

SHOTCRETE TECHNOLOGY CONFERENCE

Tuesday, March 13, 2018 | AIA CEUs available

Speaker	Presentation
Dominic Petrella	Recognizing and Avoiding Shotcrete Finishing Mistakes
Oscar Duckworth	Are We There Yet? Hybrid Placement Techniques
Oscar Duckworth	Thixotropy — What Does it Have to Do with Shotcrete?
Patrick Bridger	State-of-the-Art in Shotcrete Equipment
Rusty Morgan	The Evolution of Underground Shotcrete
John Zhang	Transport Properties of Shotcreted and Cast Concrete
Bill Drakeley	State-of-the-Art in Shotcrete Pool Design and Construction
Dominic Reda	Design and Construction Aspects of Shotcreted Final Tunnel Linings
Marc Jolin	Shotcrete R&D in the Next 25 Years: What to Expect
Kyong-Ku Yun	Cellular Sprayed Concrete: An Innovative Method for a Variety of Applications
Bill Geers	Advancements in Steel Fiber Reinforced Shotcrete for Underground
William Clements	Innovative Shotcrete Technologies for Underground Development and Infrastructure Repairs
Axel Nitschke	Specification and Design of Shotcrete for Road Tunnels
Adrian Hedström	Virtual Training and Certification for Mechanized Shotcrete Spraying — New Procedures in Australia and Sweden
Terry Lee	Why Natural is Better – Benefits of Natural Fibers in the Concrete Curing Process
"Sash" Williams/Rick Shone	Wine Caves of California
Bill Allen	Equipment Safety: Prevention through Design
Stephen Tadolini	Fiber-Reinforced Ultra-Rapid Hardening Sprayed Concrete for Civil and Construction Applications

Sunday, March 11, 2018

CONTRACTOR QUALIFICATION SEMINAR

8:30 AM – 5:00 PM | Room: Buena Vista/Sutter Home

Fees: $600 first registration | $450 subsequent registrations from same company (publications/written exam not included)

ASA is pleased to launch this long-awaited program as an optional event at our 20th Anniversary Shotcrete Convention! A compilation of seven shotcrete-related ASTMs, ACI 506R-16, "Guide to Shotcrete," ACI 506.2-13, "Specification for Shotcrete," ASA's Safety Guidelines for Shotcrete, the 90-minute written exam, and lunch are all included with registration fee.

One of the mandatory requirements in this new ASA Contractor Qualification Program (CQP) is the attendance of a company representative at a full-day Contractor Qualification Seminar presented by ASA. The seminar focuses on the many aspects of successful shotcrete contracting and how shotcrete construction compares to more traditional form-and-pour concrete construction. The seminar is geared toward education of Contractors but may be valuable to Owners, Engineers, Architects, and Suppliers who want to learn more about the details required to consistently construct high-quality, durable concrete structures with shotcrete placement.

Topics covered in the seminar include: Overview of the CQP; Site planning/Logistics; Diversity of Shotcrete Applications; Concrete Knowledge; Shotcrete Equipment; Shotcrete Knowledge; Shotcrete Testing; Equipment Maintenance; Shotcrete Specific Safety; and Financial Responsibilities.

Attendees seeking Shotcrete Contractor Qualification for their company (one representative per company) will be required to take a written examination at the conclusion of the seminar.

ASA GOLF OUTING

8:00 AM start | Tee times tiered 10 minutes | Approximately 4.5 hours on the course | Meet: Silverado Pro Shop | Fee: $195 pp, guest: $175 (1 only, guest registration required) | $65 optional club rental

ASA's first Golf Outing will be held at Silverado's newly renovated North Course, which recently hosted the PGA Tour's Safeway Open Champions (October 2017). This course has a rich history of tournament play with past winners such as Nicklaus, Sneed, Miller, Watson, and Trevino.

The outing should provide an excellent social opportunity to share a round of golf on a tremendous course. Space will be limited so register early to reserve your spots. Lunch is included with your registration.

NAPA VALLEY BIKE TOUR

9:00 AM – 12:00 PM

Fee: $90 pp (subject to cancellation if minimum not met)

Napa Valley's exquisite vistas and rolling hills make the perfect setting for a bike tour! This three-hour guided tour includes plenty of ride time as well as stops along the way with great photo opportunities! Enjoy the fresh air and sunshine as you ride along country lanes with vineyards at your side. The tour will start and end at Silverado and includes bike rental, helmet, water, and snacks.

LEGENDARY WINE TOUR

10:00 AM – 4:00 PM

Fee: $110 pp | Wine tasting fees $25-$40 pp. not included

The Napa Valley is North America's legendary wine capital from which hundreds of wineries provide their ambrosia to discerning patrons. A few particularly famed wineries set the cornerstone from which this reputation was built. Sample wineries for this tour include: Beringer, Mondavi, Inglenook, and Charles Krug, with a stop for lunch (on your own).

Monday, March 12, 2018

SHOPPING TOUR

Downtown St. Helena and Yountville | 10:00 AM – 3:00 PM | Fee: $55 pp

A visit to Napa Valley is not complete without a respite for browsing and shopping in St. Helena and Yountville. There is something for everyone... the sophisticated shopper's paradise. This will give the group an opportunity to refresh, relax, rejuvenate, sip coffee, or even taste olive oil prior to dinner... or simply enjoy a stroll along the flower bed lined streets, enjoy casual patio dining, a leisurely lunch overlooking a vineyard, or a cappuccino and croissant curbside. It's your choice as you discover the magic in both of these quaint but world-renowned Wine Country towns.

Round trip bus includes 2 hours shopping and dining time (on your own) in St. Helena and Yountville plus a short tour of Legendary Napa Valley.

COMMITTEE DINNER/GOLF AWARDS

6:00 PM – 9:00 PM | Room: Mansion Gardens

Fee: $125 pp; guest: $100 (1 only, guest registration required)

The Mansion Gardens is Silverado's newest outdoor/indoor venue. With 18,000 ft2, it features Napa Valley-style gardens including a small vineyard, a spacious lawn, and a 5000 ft2 seasonal pavilion for receptions, dinners, and meetings. A buffet dinner, drinks, and acknowledgements for Sunday's golf outing is included. This dinner provides another opportunity to network with your colleagues and serves as the optional Committee Dinner normally enjoyed after Committee Meetings.

Tuesday, March 13, 2018

CHEESE MAKING CLASS

10:00 AM – 11:30 AM | Room: TBD

Fee: $120 pp (subject to cancellation if minimum not met)

Our expert host breaks down the barriers to cheese making, making it accessible, easy, and fun with energetic, hands-on classes that teach participants how to craft a fresh, warm ricotta cheese that is ready to serve and enjoy within 90 minutes.

Upon arrival, guests are welcomed with locally crafted wine and an artisanal cheese tasting, allowing them to explore different types of handcrafted cheeses prior to creating their own. Next, Sheana Davis leads participants in the interactive process of making a fresh ricotta cheese. All ingredients used are readily available in any local grocery and the cooking supplies used reside in most home cook's kitchens.

Participants work in a group to create the cheese: they pour the milk, ladle and scoop the curds, and within 60 minutes they have a delicious, fresh ricotta cheese ready to be enjoyed by the group. Upon completion, Davis shares various seasonally inspired ways to serve the cheese, using local herbs, jams, and produce. All participants leave with their own cheesecloth and ladles to continue the cheese making experience at home.

OUTSTANDING SHOTCRETE PROJECT AWARDS BANQUET

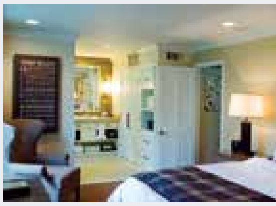
5:15 PM – 10:30 PM | Inglenook Winery | Fee: $250 pp (convention registration required); guest: $200 (1 only, guest registration required)

ASA's Annual Outstanding Shotcrete Project Awards Banquet has been a highlight event for the industry these past twelve years. Normally held in conjuction with the World of Concrete in Las Vegas, we are excited to host this year's celebration at this Napa Winery!

Enjoy breathtaking views of the estate vineyards as you arrive, continuing through the expansive courtyard to the grand chateau, where you will be greeted with tray-passed wines. During the reception preceding dinner, you may enjoy a tour of the Infinity Caves, peruse the various historical areas, the extensive Rubicon gift salon, or simply enjoy the wine and hors d'oeuvres. A sumptuous pairing dinner follows in our majestic Barrel Room, which boasts the original carriage doors, towering ceilings, and turn of the century 1000-gallon casks. Fee includes round trip transportation from Silverado.

RESERVATIONS AND REGISTRATION

SILVERADO RESORT AND SPA

1600 Atlas Peak Road, Napa, CA 94558 | www.silveradoresort.com

DETAILS AND RESERVATIONS

Silverado Resort and Spa is a luxury resort in the heart of the world-famous Napa Valley Wine Country. Whether you come to the Northern California area for relaxation, adventure, or business, you will find it all here. Located just an hour north of San Francisco, CA, it's all tucked away from the city while still being close to the Bay Area action. The soothing, full-service spa sets the stage for relaxing comfort, offering massages, facials, manicures, pedicures, and more. The resort offers two PGA championship golf courses, overseen by World Golf Hall of Fame member, lead golf analyst for NBC Sports, and resort co-owner Johnny Miller; 13 lighted tennis courts; and biking and hiking trails. Thanks to its Napa Valley location, it is close to more than 400 wineries.

Stay with Us and Support ASA

ASA has negotiated extremely favorable rates with Silverado for your convenience. By staying at our Host Resort, you will be closest to all the action while helping your Association meet our commitment to Silverado to obtain these rates. When making your reservations, consult the convention schedule and take your level of convention registration into consideration. If you are planning to attend the full convention, we recommend you begin your resort reservations on Sunday, March 10, 2018. For the Tuesday Shotcrete Technology Conference registration only, we recommend you reserve both Monday and Tuesday evenings (March 12-13, 2018) to accommodate the full Tuesday schedule.

ROOMS

Rates (per night): Standard room — $169; Junior Suite — $219; One Bedroom Suite — $259.

RESERVATIONS

Deadline to secure negotiate rates: February 5, 2018. Please reserve online to access our special rates: **https://aws.passkey.com/e/49267611**. To reserve by phone, please call +1.800.532.0500 and identify yourself as being with ASA and the Shotcrete Convention. All reservations are on first-come, first-served basis. Check in time is 4 p.m., check out time is 11 a.m. If you arrive earlier, or need to stay on site after check out, the resort will securely store luggage until you need it.

RESORT FEATURES

Silverado Resort and Spa offers many activities including hiking, biking, bocce, tennis, swimming, and a fitness center with complimentary classes included with your resort fee. Additionally, you will find Silverado equipped with many fine dining options, PGA championship golf courses, and a full-service spa.

SHOTCRETE CONVENTION & TECHNOLOGY CONFERENCE

Full Package: Sunday-Tuesday, March 11-13, 2018. Includes 4 breakfasts (S, M, T, W), 1 lunch (T), all meetings (S, M, T unless listed as Ticketed Event). Saturday evening arrival and Wednesday morning departure recommended.

Tuesday only: Includes two breakfasts (T, W), one lunch (T), and meetings (T). Monday evening arrival and Wednesday morning departure recommended.

Guest Registrations: Includes all corresponding meals and complimentary resort features, no meetings.

Registration Deadline: Register by January 9, 2018, to be entered for a drawing for a complimentary full-page color ad ($1920 value) in the Spring 2018 Awards issue of *Shotcrete* magazine.

Registration Form available until March 2, 2018. Form may be used for one Attendee and one Guest: www.shotcrete.org/registration.

Cancellation Policy: ASA will refund the registration fees for any cancellations received by Friday, February 23, 2018, minus a $100 cancellation fee (Golf Outing subject to an additional cancellation fee of $50). NO registration refunds can be given for cancellations after February 23, 2018.

Convention/Conference Registration	Member Rate	Nonmember	+ Late Fee (after Feb. 5)
Full Package Attendee	$425	$500	+ $100
Full Package Guest	$275	$275	+ $50
Tuesday Only Attendee	$325	$400	+ $100
Tuesday Only Guest	$175	$175	+ $50
Optional Ticketed Events (flat rates)	**First Attendee**	**Additional Attendee** (same company or Guest)	**Day of Event**
Convention or Conference registration **required** for the following:			
Contractor Qualification Seminar	$600	$450	Sunday
Golf Outing (club rental available)	$195	$175*	Sunday
Napa Valley Bike Tour	$90	$90	Sunday
Legendary Wine Tour	$110	$110	Sunday
Shopping Tour	$55	$55	Monday
Committee Dinner/Golf Awards	$125	$100*	Monday
Cheese Making Class	$120	$120	Tuesday
Awards Banquet	$250	$200*	Tuesday

*Discounted Additional Attendee rates apply to registered Guest attendees only

History of Wire-Wrapped Circular Prestressed Concrete Tanks

By Lars Balck and Daniel McCarthy

Circular wire-wrapped prestressed concrete tanks and "gunite" (dry-mix shotcrete) evolved together early in the 20th century. The flexibility and economy of the shotcrete process facilitated development of the early prestressed circular water tanks (Fig. 1). One of the engineers that developed gunite also developed prestressing for cylindrical concrete tanks. Thus, the two technologies (shotcrete and wrapped prestressing) are, on some level, sister technologies.

SHOTCRETE, AKA GUNITE

Shotcrete is the process of pneumatically accelerating concrete to high velocity to compact the concrete material upon impact. The process of conveying a dry mixture of sand and cement through a hose, with water being added at the nozzle at the end of the delivery hose, was coined "gunite" by an early equipment manufacturer. The term "gunite" is often used today, but because it was a proprietary trade name, the American Concrete Institute (ACI) has adopted the term "dry-mix shotcrete." Additionally, the process of shooting already-mixed concrete, using concrete pumps with air added at the nozzle to accelerate the mixture, was designated as "wet-mix shotcrete."

Fig. 1: Early prestressed shotcrete storage tank—circa 1936—in continuous maintenance-free service for more than 70 years

A crude form of "shotcrete" is early masons hand-throwing mortar into place. In 1907, Carl Akeley, a naturalist looking for a way to make durable models, devised a method to spray a dry sand-cement mixture with water being added at the nozzle (gunite). The machine was able to place mortar with sufficient velocity to compact the mortar, which is a characteristic not achievable with hand-thrown mortar. In addition, mechanizing the process allowed for greater production.

Akeley's invention quickly drew the attention of investors who saw the invention's potential, and for 4 years they tried to market the cement gun with Akeley. Samuel Traylor of Traylor Engineering and Manufacturing; a munitions manufacturer who had done well due to World War I, also realized the potential of the cement gun and in 1916, when Akeley's group failed, he bought all rights and started the Cement Gun Company.

Traylor saw the gun's potential was not just in manufacturing guns, but in construction. He immediately started the construction company, Traylor-Dewey Contracting, that specialized in the newly trademarked "gunite" construction using the cement gun. Traylor upgraded the gun by improving the manufacturing process, and with assembling a skilled placement crew, thus controlled the complete process. The Cement Gun Company went on to publish engineering articles about the success of the projects they undertook, and of the superior properties of gunite, which attracted the attention of engineers and helped gunite construction expand along with increased production of the cement guns.

PRESTRESSED CONCRETE

Concrete developed by the Romans over 2000 years ago was only used in gravity compression structures such as columns and arches. Later, around 1850, European engineers produced and developed a major technological improvement, "reinforced concrete," by at first adding iron chains and, in further development, steel bars. The addition of steel allowed a concrete member to take some tensile stresses along with the compression stresses.

Reinforced concrete permitted a structural member such as a beam to resist bending, and beams could be used in bridge and building construction. In a simply supported beam, the top of the concrete beam is in compression while the bottom is in tension. Reinforcement is placed in just the bottom portion of the beam to carry the tensile forces. To increase a beam's capacity, more steel can be added, but then even more concrete must also be added, causing an increase in the beam's dead weight. The full capacity of both the concrete and steel is not being used, but the reinforced concrete design improved the application and versatility of concrete in structures.

In the early 20th century, the development of prestressing concrete became the second major advancement in concrete technology. In a prestressed member, the full concrete cross section is in compression by pretensioning high-strength steel in the member. Prestressed concrete allows for the full use of the properties of both concrete and steel. Prestressed concrete has allowed designers to build a wider range of concrete structures using less material and often reducing costs.

Compression of a circular vessel is an old idea. For 2000 years, wood wine barrels have been manufactured with wood staves and compressed together with steel rings. Early gun barrel manufacturers wrapped the barrels with wire to help contain the expansive pressures produced in gun barrels.

With the development of high-strength steel wire, engineers began applying the same "hoops around a barrel" principal to the circumferential compression of concrete tanks for liquid storage for three reasons:

1. **Crack resistance**. By keeping concrete subject to tension in compression, cracks are minimized or eliminated. Concrete cracking and the resulting leakage due to hoop tension from outward hydraulic forces of non-prestressed concrete water-retaining structures has long been a problem for engineers.
2. **Durability**. Concrete has demonstrated long-term durability in environments with constant exposure to water, wastewater, and other liquids.
3. **Cost savings and sustainability**. Because prestressing uses concrete in compression and steel in tension better, prestressed concrete tanks require fewer materials (40% less concrete and 60% less steel) than equivalent form-and-pour concrete tanks. Fewer materials result in significant cost savings.

Successful prestressing of concrete began with Eugene Freyssinet in Europe in the late 1920s. Freyssinet, in 1933, published an article, "New Ideas and Methods,"[1] which outlined "conditions for the practical use of prestressing"—the basis of prestressed concrete that included compressing high-strength concrete by tensioning high-strength steel. At that time, American engineers were suspicious of European engineers; however, some Americans realized the potential of prestressed concrete. One engineer was W. S. Hewett.

While Freyssinet was working on linear prestressing to build bridges in Europe, W. S. Hewett, an American bridge builder in the United States, began building circular prestressed tanks using rods and turnbuckles. Hewett felt concrete (because of its durability) was the best material for construction of hydraulic structures. He also understood that the existing relatively low-strength steel rods didn't have sufficient strength to apply the force required to keep the concrete wall in compression due to the shortening of the concrete (shrinkage) and relaxation (elongation) of the steel.

J. M. Crom, an American engineer and associate of Hewett, picked up where Hewett left off and thus escalated the connection between shotcrete and prestressing.

In 1918, Crom was a salesman and manager for the Chicago, IL, office of Traylor's Cement Gun Company. Crom sold cement guns for 4 years and was one of the top salesmen. After a disagreement with the Cement Gun Company, he moved to Texas and started a gunite firm, Crom & Lindberg, where he shot gunite drainage canals along the Rio Grande. He even patented equipment to improve the efficiency of placing canal linings. Crom was a prolific inventor and had at least 40 patents mostly for shotcrete application and prestressed tanks (and one for an automatic baseball machine).

In 1929, Crom, along with John H. Hession and Andrew Lindberg, started a new company, National Gunite Corporation, for gunite construction, based in Boston, MA. Of course, the Great Depression hit in 1929, and consequently was not a great time to start a new company. But they prevailed and were successful in renovating buildings with gunite.

Early on, they became interested in prestressed concrete tanks due to Hewett's work and formed a second firm, The Preload Company, for building prestressed tanks using gunite. Because of Freyssinet's and Hewett's work, Preload started an intensive research program in 1933 in conjunction with the Massachusetts Institute of Technology (MIT) and other prominent scientific institutions in the United States and Canada to understand shrinkage, creep, and relaxation of high-strength prestressing steel. By the 1940s, with the knowledge gained from research and the availability of high-strength wire, they were confident they could build a prestressed concrete tank. All that was needed was a machine to place the high-strength wire.

Preload built a machine to continuously wrap fully tensioned prestressing wire in a helical pattern around the circular shotcrete tank. In 1941, Preload built the first wire-wrapped circular tank in Indian Head, MD. The high-strength wire allowed the application of sufficient force to overcome the wall shortening due to shrinkage and creep of the concrete and relaxation of the steel, while keeping the concrete in compression to fully resist the outward pressure of the contained water. Crom, through Preload, ultimately patented the complete tank building system.

Crom also developed a patented composite wall system for construction of watertight tanks. The composite system involved encasing a continuous steel shell with gunite to form a watertight tank wall and provide vertical reinforcement. With these patents, Preload soon advertised crack-free, watertight concrete tanks.

The early circular prestressed tanks were often built completely with gunite: floors, walls, and dome. But that should be no surprise. Both Crom and Hession were gunite contractors and at that time gunite strengths—regularly 8000 psi (55 MPa) or more—were significantly greater than typical 1-2-3 concrete mixtures yielding 3000 psi (20 MPa). Additionally, gunite delivery through a flexible hose provided an easy method of conveying a concrete mixture to the placement location.

The 1940s were a wild time for Preload. Preload had successfully built what engineers had tried to achieve for a long time: a truly prestressed tank. Of course, there was World War II. Steel for the war effort (battle tanks and munitions) was in great demand, so the government purchased concrete water tanks instead of steel water tanks, further increasing the demand for the new prestressed concrete tanks.

Soon, the rapid success of prestressed tanks caught the attention of investors such as John A. Roebling of Roebling & Sons Corporation in 1947, whose business sold prestressing wire. Roebling acquired controlling interest in late 1951, which they held through 1953. For the next several years, the company undertook a domestic and international licensing program. Negotiations during this period resulted in the sale of Preload to the Holly Corporation in 1956.

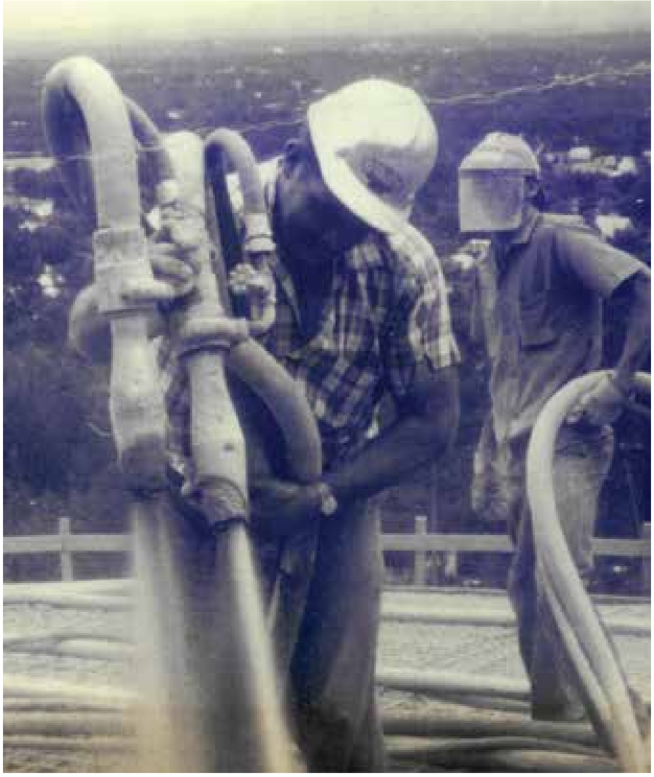


Fig. 2: Placing dry-mix shotcrete using dual nozzles to increase production when shooting a free span 3 in. (76 mm) thick dome circa 1965

One of the problems in the early tanks was early deterioration of some of the gunite domes. Prestressing the dome ring at the top of the wall allowed for the construction of a highly efficient and economical free-span concrete dome. Placing dry-mix shotcrete on a horizontal surface is difficult. Rebound and overspray is easily trapped when shooting at your feet and sand lenses can form, permitting water from both rain on top and condensation from the underside of a dome to accumulate in the sand lens. This led to deterioration of the gunite domes shot by lesser-experienced nozzlemen in freezing-and-thawing environments. Even though the majority of gunite domes never experienced problems, several domes required expensive repair. Experienced, diligent nozzlemen, with the proper technique, usually had good success (Fig. 2). In the 1970s, with the availability of concrete pumps, domes could be cast in a day or two rather than taking weeks to shotcrete, so it became much more economical to cast rather than shoot the concrete domes covering the circular tanks.

The 1950s brought further change. John Hession, the cofounder of Preload, resigned in 1950 as President. Hession still owned National Gunite and, in 1955, partnered with Preload engineer Francis Crowley to start a new company, Natgun, as a subsidiary to National Gunite to build prestressed tanks. Soon, the general gunite business was dropped in favor of focusing on tank construction. Hession financed the new company while Crowley, who "didn't have two nickels to rub together," ran the company. Together they created a successful tank company. In 1991, when Crowley passed away, his two sons took over running the company.

At nearly the same time that Hession resigned from Preload, the other cofounder, J. M. Crom, retired from Preload and moved to Florida, where in 1953, with his sons Ted and Jack, formed The Crom Corporation to specialize in building of composite prestressed concrete tanks. Crom retired a second time in 1957 and his two sons took over the business from their father. However, the two sons split the company into two separate firms in 1961, with Ted operating on the East Coast and Jack on the West Coast.

There were other changes in the 1950s. After Hession retired, Curzon Dobell, a Canadian, became President of Preload. Max Dykmans (who was a Japanese prisoner of war for 4 years) joined Preload in 1952 in New Zealand and in 1957 moved to New York to became Vice President of Engineering and Operations. Dykmans left Preload in 1961, moved to California, and established BBR Prestressed Tanks. Dykmans was another prolific inventor with over 50 patents, primarily for equipment to prestressing tanks and concrete nuclear containment vessels. Dykmans' sons would start DYK Prestressed Tanks in the early 1980s. Interestingly, in 2010, the sons of both DYK and Natgun, who had been fierce competitors for years, merged to form a new prestressed tank company, DN Tanks.

After the Holly aquistion in 1956 of Preload, the domestic licensing program was halted, and the company began to reconsolidate. The company, which had designed and built the first prestressed concrete bridge in North America in 1950 (Walnut Lane Bridge in Philadelphia, PA) and many similar bridges, turned focus back to circular tanks. In 1961, Andy Tripp and Jack Hornstein, both long-time employees of Preload, bought Preload from the Holly Corporation. They would go on to expand Preload's work from water tanks to include large and complex liquified natural gas (LNG) storage tanks, building off their earlier 1955 invention of cryogenic storage tanks for liquid oxygen. Andrew E. Tripp Jr., son of Andy Tripp, still serves as Preload's President today.

TODAY

Shotcrete continues to be an integral part of wrapped prestressed tank construction. Although floors and domes are generally cast concrete, all the prestressed tank builders use shotcrete for embedment and protection of the highly stressed prestressing wire or strand. Cement-rich shotcrete provides excellent corrosion protection to the steel, and easily accommodates the curved surfaces without formwork. A couple of tank builders use shotcrete for construction of the entire vertical prestressed concrete wall using an embedded steel diaphragm for liquid tightness. These tanks are massive structures, ranging from a capacity of under 100,000 gal. (380,000 L)[1] to over 30,000,000 gal. (110,000,000 L).[1] Diameters range up to 350 ft (100 m) and with wall heights up to 70 ft (20 m).

Today, five companies specialize in the construction of prestressed tanks and have built over 8000 prestressed concrete tanks worldwide over the past 75 years. Although equipment and construction techniques have certainly been refined and productivity increased over the last 75 years, the circular wrapped prestressed ground storage tanks built today are basically using the same design principles initiated by the Preload Company in 1941.

References

1. Freyssinet, E., "New Ideas and Methods, A Half Century of French Prestressing Technology," special English edition of *Travaux* 50, Apr.-May 1966, pp. 607-622.

Lars Balck *is a Concrete Consultant and ASA/ACI Nozzleman Examiner. He recently retired from CROM, LLC, as a Senior Vice President. He has been involved in the design and construction of prestressed concrete tanks built with shotcrete for over 40 years. He received his bachelor's degree in civil engineering from the University of Florida and served with the U.S. Army as First Lieutenant in Vietnam as a Combat Engineer. Balck is a Past President of ASA. He is Chair of ACI Subcommittee 506-C, Shotcreting-Guide; a past Chair and current member of ACI Committee 506, Shotcreting; and a member of ACI Committees 376, Concrete Structures for Refrigerated Liquefied Gas Containment; 563, Specifications for Repair of Structural Concrete in Buildings; and C660, Shotcrete Nozzleman Certification.*

Daniel McCarthy *is Vice President of Engineering & Construction Performance at Preload, LLC., of Louisville, KY. He has specialized in the evaluation, design, and construction of wire-wrapped tanks since 1982. He is a Fellow of the American Concrete Institute (ACI) and Chair of ACI Subcommittees 350-H, Editorial, and 350-L, Specification; past Chair of ACI Committee 372, Tanks Wrapped with Wire or Strand; past Secretary of ACI Subcommittee 350-E, Precast-Prestressed; and a member of ACI Committees 350, Environmental Engineering Concrete Structures, and 437, Strength Evaluation of Existing Concrete Structures, and Joint ACI-ASCE Committee 423, Prestressed Concrete. A graduate of the University of Connecticut and Columbia University, McCarthy is a licensed professional engineer in 36 states and the District of Columbia.*

The Evolution of Shotcrete Evaluation and Testing

By George Seegebrecht

The versatility of concrete is truly impressive. Changing the concrete aggregate type, gradation, or removing a portion of aggregate can change common concrete to become lightweight, heavyweight, or pervious concrete, to list a few types. Using today's admixtures, concrete can be accelerated, retarded, or suspended in its setting behavior, allowing wider possibilities in concrete placement.

Changing placement methods from concrete truck chute, bucket, or pumping allows placement of concrete over longer distances, at greater elevation changes, or on steep slopes, and in extreme climates.

Shotcrete enhances the creativity and versatility of concrete. The dry-mix shotcrete process (originally trade-named gunite) pneumatically propels concrete materials under pressure to the nozzle at the end of the hose, where water is added to the materials stream. The wet-mix shotcrete process pumps fully mixed concrete through the hose, where at the nozzle, air flow is used to produce high velocities that compact the materials on impact. Also referred to in Europe as "sprayed concrete," shotcrete is conveyed under pressure at high velocity so consolidation is achieved instantly upon impact. The shotcrete process allows concrete to be placed without forms, into complex shapes, vertically, and overhead. Shotcrete has been the construction tool of choice for pools, tunnels, domes, tanks, foundation walls, soil stabilization, and a wide range of repairs in easy-to-reach or seemingly inaccessible locations.

To determine if this rapid placement process is successful, testing is necessary to verify that the shotcrete applied is of good quality, both strong and durable. Differences between shotcrete and form-and-pour concrete are primarily in the placement method and, to a degree, in the concrete materials and admixtures. Like other unique concretes, testing specific to shotcrete was needed to provide assurance that the applied materials will perform the intended function and exhibit durability for the design life required.

SHOTCRETE EVALUATION AND TESTING THROUGH THE YEARS

Before progress can be made in testing a material, an accepted name had to be established. Formed in 1904, the American Railway Engineering Association (AREA) adopted the term "shotcrete" circa 1930 to encompass the many proprietary names generated for the dry-mix process that had appeared in addition to "gunite," such as: guncrete, blastcrete, jetcrete, spraycrete, spritz-beton, and so on.

In 1942, the American Concrete Institute (ACI) formed Committee 805, "Recommended Practice for Pneumatically Applied Mortar." ACI 805-51, in the introduction (excerpted in the following paragraph), established a consistent term in the interest of clarity. The term "shotcrete" was set by the committee as the nomenclature for the remainder of the document.

"To avoid the cumbersome term 'pneumatically-placed mortar' the word 'shotcrete' is used to refer to this material in the remainder of this report."

This helped standardize the use of the term in the United States. By contrast, Europe and other parts of the world adopted the term "sprayed concrete."

ACI Committee 805 was retired after completion of the Practice Recommendation, but in 1957, ACI Committee 506, Shotcreting, was created, and in 1960 organized to revise and update the recommended practice for shotcreting. ACI 506 Chair Thomas J. Reading stated in the preface to publication SP-14, *Shotcreting*, that the committee quickly found there was a scarcity of engineering data on shotcrete, its properties, and performance. Also, that there was an obvious need for better guidance for field personnel who apply shotcrete and for the designer as to what can reasonably be expected of the material. The committee sought out the shotcrete-related input of committee membership including most knowledgeable engineers, shotcrete contractors, equipment manufacturers, general contractors, admixture manufacturers, federal and local government representatives, port authorities, and the Portland Cement Association to address this deficiency in guidance.[1-3]

ACI Committee 506, Shotcreting, has since sponsored many ACI symposia and seminars, and produced numerous documents to aid those working with shotcrete in the recommended practice and specifications and use of shotcrete in a variety of above-ground and underground applications.

RAPID IMPROVEMENTS IN SHOTCRETE

According to George D. Yoggy in his "History of Shotcrete" series,[1] the years following World War II saw rapid change and improvements. The shotcrete industry was introducing new technology and producing the first significant equipment changes since the original invention in 1907.

In 1957, the rotary gun was introduced and not only enabled easier operation but could also incorporate larger-sized aggregate into the mixture. The "continuous feed" guns made a significant change in the industry, allowing for the successful delivery of relatively higher production rates. Many are still in use today, incorporating various batching, mixing, and feeding mechanisms.

Rapid growth frequently comes with growing pains. After shotcrete's first 40 years of outstanding growth and success, the dry-mix process improvements and wider industry acceptance drew many into the industry. Was the growth so fast that it was uncontrolled? Did the new machine developments make operation so easy that training seemed no longer necessary? A period of poor workmanship soon followed in the 1970s, resulting in damage to the reputation of shotcrete as a reliable process.

Those knowledgeable in the shotcrete industry knew corrections had to be made to regain the true image of the process that, when properly designed and executed, produced high-quality, durable in-place concrete. The righting of the ship was again due to the work of dedicated industry individuals who provided their experience to restore the standards the industry needed. Names of notable individuals that contributed are listed by George Yoggy in his "History of Shotcrete" article and included: Crom, Maier, Fredricks, Reading, Moore, Carroll, Truman, James Warner, Esposito, Rappa, Zynda, Lorman, and Leon Glassgold. But of course, this list is incomplete, as it continues to grow every year, including names like Yoggy, Litvin, Gebler, Rizzo, Morgan, and more recently research and testing by Jolin and Zhang.

In the 1960s, Joseph J. Shideler and Albert Litvin at the Portland Cement Association R&D Labs prepared numerous papers[4,5] detailing both wet and dry shotcrete processes covering all aspects of equipment, mixture designs, crew duties, gunning procedures, finishing, and curing.

They presented papers reporting shotcrete laboratory studies on 39 shotcrete mixtures in *Shotcreting*, an ACI Special Publication.[5] Studies reported tests conducted on test panels submitted by numerous contractors and equipment manufacturers. Tests were conducted to compare quality of shotcrete produced by various types of equipment commonly in use at the time. Test data was obtained to determine material properties of each submitted shotcrete panel and included data such as: compressive and flexural strength, modulus of elasticity, drying shrinkage, creep, absorption, freezing-and-thawing durability, and permeability.

Initially, shotcrete was tested using established cast concrete tests. ASTM standard concrete test methods for concrete were used to qualify the individual constituents of shotcrete-making materials, but there was a need for ASTM International to develop new standards specific to shotcrete materials and testing. ASTM International established a subcommittee of Committee C09, Concrete and Concrete Aggregates, in the 1990s to develop standards for shotcrete testing. (The six shotcrete-specific ASTM Standards developed by the ASTM Subcommittee C09.46, Shotcrete, are described later in this article.)

Pre-construction test panels: Used when a project has heavy, congested reinforcement in the structural sections to be shot. The test panels are fabricated with reinforcing steel to mirror the type of congestion that is to be expected in the project, and are used to qualify three different aspects of the shotcrete: 1) the material being shot; 2) the equipment used for shooting; and 3) the nozzleman doing the shooting. Sometimes used to establish architectural texture and color of finished shotcrete.

Material test panels: Used to provide QC/QA for materials being shot on a project. ACI 506.2 specifies a panel a minimum of 16 x 16 x 5 in. (400 x 400 x 125 mm) for panels. These panels are not reinforced, and are usually shot with a frequency of every 50 to 150 yd^3 (38 to 110 m^3) or if shooting lower volumes, at least once a day. Cores for compressive strength testing or other physical properties are extracted from the panels.

Fresh concrete testing: Concrete to be shotcreted is often tested for slump, air content, concrete temperature, and density. The tests are usually run at the point of delivery—at the pump for wet-mix and at the nozzle for dry-mix.

Hardened concrete testing: Hardened shotcrete properties are normally determined by laboratory testing. Usually samples are extracted from the previously prepared test panels. Cores may also be extracted from the in-place structure for testing. Cores are routinely used to test for compressive strength, but may also be used for permeability, density, or hardened air void analysis.

Compressive strength testing: The most common acceptance method for concrete. Usually measured at 28 days, but often checked other times such as 3, 7, and 14 days, to get an earlier indication of the probable 28-day strength.

Flexural and toughness testing: Flexural properties are usually only required for fiber-reinforced shotcrete (FRS), and predominately used for underground applications. When FRS is specified, flexural strength and residual strength are evaluated using beams sawed from test panels. For toughness, round panels are shot and tested in accordance with ASTM C1550.

Source: Hanskat, C. S., 2011, "Shotcrete Testing—Who, Why, When, and How," *Shotcrete*, V. 13, No. 3, Summer, pp. 8-12.

Many researchers, engineers, and contractors have conducted comprehensive testing programs to characterize shotcrete properties. It was a blessing to work at PCA's Construction Technology Laboratories (CTL) with two previous ACI 506 Chairs in Albert Litvin and Steve Gebler, who have

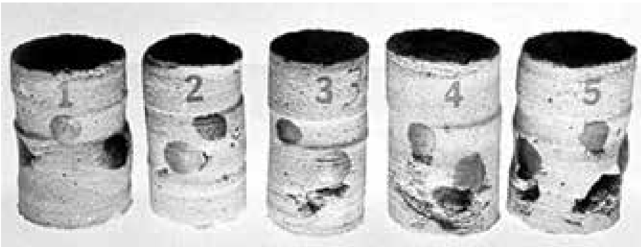


Fig. 1: When developed, the core grading system was used to judge the skill of the nozzleman to encapsulate reinforcing steel. Degree of voiding, presence of sand seams, and encapsulation of reinforcing steel were the focus of visual observations of the cores. However, the process was judged to be flawed. Many questioned the approach as too subjective and variable due to shotcrete experience of the evaluator. Significant differences between those grading cores yielded significantly different results that ranged from passing (grade 1-2-3) to failing (grade 3-4-5) results on the same set of cores. Some specified core grades that were higher than necessary for certain jobs, causing good-quality materials to be questioned or rejected when its performance would have more than met service requirements

Fig. 2: Visual observation during shotcrete observation may note improper shooting techniques, resulting in inclusion of voids or rebound materials with low integrity where it matters most. Laboratory tests of panel cores do not address this issue, as it is related to shooting technique in this location. Visual examination for cracking patterns, supplemented by hammer sounding (ASTM C4580-12) to detect hollow/delaminated areas for closer study, and possible coring for laboratory testing where relevant properties can be determined

Fig. 3: Visual inspection of cores extracted from structures with unusual cracking or leaking can help to reveal improper shooting techniques or poor materials. All concrete has some degree of void or less than perfectly consolidated materials. Using an ACI Certified Nozzleman and crew that works well together to avoid inclusion of rebound is critical

developed and conducted many testing programs, and in my case, supervised and mentored through numerous projects.

Steve Gebler conducted many testing programs including assessments of the durability of dry-mix shotcrete and the durability of dry-mix shotcrete with rapid-set accelerator, as well as the strength, bond, and durability of shotcrete used in the repair of East Coast concrete cooling towers. He was passionate about shotcrete and wrote numerous articles regarding the core grading system, shotcrete tolerances, and shotcrete pool construction.[6-8]

When receiving field-shot test panels, they were cored in the laboratory to obtain specimens to determine properties including compressive strength, hardened concrete air voids, freezing-and-thawing performance, chloride ion penetration, specific gravity, and boiled water absorption.

The difference in the placement method is significant. For instance, with form-and-pour concrete, strength test specimens are cast as cylinders. With shotcrete placement, the impact, air flow, and production of rebound prevent representative specimens to be produced in cylinder molds. Thus, shotcrete compressive strength specimens are cored from standardized test panels.

To assure the ACI Certified Nozzleman can adequately encapsulate reinforcement configurations on a specific project, qualifying test panels are prepared and shot for subsequent coring to assess shotcrete placement around reinforcing bar and presence of voids and sand seams. Core "grading" was initially recommended in ACI 506.2-95, "Specification for Shotcrete," for evaluation of test panels, but the system has fallen out of favor due to the subjective nature in rating cores by inexperienced engineers or inspectors (Fig. 1). In our office, with our ample shotcrete experience, the core grading system worked well. On specific evaluations, the core grading was done by multiple (three) engineers independently and then averaged. If major discrepancies occurred, discussions were held, field observations added, additional cores were examined, or in extreme cases, supplemental cores were taken.

In the field, another form of testing starts with visual inspection (Fig. 2 and 3) by experienced shotcrete practitioners. Batching and mixing in the field should be observed to assure that they follow ASTM and ACI requirements for shotcrete materials. Prepackaged materials used in the dry-mix process should be pre-dampened just before use.

Inspection to visually note unintentional textural changes could signal the presence of rebound or overspray included in the work.

An engineer, inspector, or contractor experienced in shotcrete can recognize poor shooting practices during installation, such as shotcrete material buildup on reinforcing steel. On completed work, it may be possible to note suspect color changes that may signal undesirable, poorly mixed shotcrete fluctuations in water/cementitious material added to the mixture.

Such observations might next lead to hammer sounding to detect soft, punky, or delaminated shotcrete. Soundings may provide indications for locating representative cores for lab or field testing. Common tests conducted included freezing-and-thawing testing (ASTM C666), compressive strength (ASTM C1604), or in repair situations, ASTM C1583 to determine the tensile strength of concrete of concrete overlain with a repair material (Fig. 4).

ASTM Specifications Addressing Shotcrete Materials and Testing

As mentioned, shotcrete differs from form-and-pour concrete in its placement method. Most hardened properties are the same as cast concrete. Initially, shotcrete tests were conducted using existing ASTM tests for concrete with modifications as necessary because of the placement method. It became evident that shotcrete placement differs enough that these aspects must be taken into consideration when sampling and testing shotcrete to assess performance and properties. In this regard, ASTM C09.46 was established to produce testing and material standards for shotcrete that could be referenced in project specifications and in technical documents from ACI Committee 506, Shotcreting. ASTM C09.46 formalized the testing methods for preparing and sampling test panels and the extraction of cores needed for compressive strength testing and other physical properties. Tests for fiber-reinforced shotcrete and packaged/preblended materials were also addressed. ACI 506 documents including a guide, specifications, and evaluation report are used with the ASTM shotcrete tests to provide a comprehensive procedure for evaluating shotcrete quality.

ASTM Subcommittee C09.46 works on the following active shotcrete standards[9]:

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

Two standards related to establishing setting time of shotcrete developed by C09.46, but withdrawn due to issues with establishing the precision statements are:

- ASTM C1117-89(1994), “Standard Test Method for Time of Setting of Shotcrete Mixtures by Penetration Resistance (Withdrawn 2003)”
- ASTM C1398-07, “Standard Test Method for The Laboratory Determination of the Time of Setting of Hydraulic-Cement Mortars Containing Additives for Shotcrete by the Use of Gillmore Needles (Withdrawn 2010)”

ASTM International also has tests that have been directly applied to use in fiber-reinforced shotcrete, including:

Fig. 4: Field testing according to ASTM C1583. Tensile bond pulloff conducted on repair using a silica fume shotcrete overlay. Setting acceptable values would be influenced by site conditions, especially the integrity of the substrate

- ASTM C1550-12a, “Test Method for Flexural Toughness of Fiber-Reinforced Concrete (Using Centrally Loaded Round Panel)”
- ASTM C1609/C1609M-12, “Standard Test Method for Flexural Performance of Fiber Reinforced Concrete (Using Beam with “Third Point Loading)”

Shotcrete technology will continue to evolve and improve with the modification of shotcrete equipment, admixture use, and the introduction of different fibers or blends of different fiber lengths and types. Testing will need to continue to track along with modern developments to optimize designs, safety, and construction efficiency.

SHOTCRETE TESTING NEEDS FOR THE FUTURE

The outlook for the shotcrete industry is bright with the nation's repair needs ahead. Both PCA economist Ed Sullivan and the Wells Fargo's Construction Optimism Quotient (OQ) index for 2016 indicate optimism is high for general construction in the future. Just look at our deteriorating infrastructure. The American Society of Civil Engineers (ASCE) 2017 infrastructure report card rates the United States' infrastructure portfolio a dismal D+ grade. Recent years of equipment and materials improvements, along with the ACI Nozzleman Certification program, position the shotcrete industry to be a popular and dependable approach for the infrastructure repair work ahead.

Real-time maturity testing is more and more popular in conventional concrete and would benefit shotcrete as well. Hurdles may include the mixture changes inherent in the shooting process and the potential damage to maturity sensors if caught in the direct flow of shotcrete. The benefits of nondestructively monitoring strength development are obviously a plus for safety, but possibly also for monitoring efficiency of curing of shotcrete.

The benefits of shotcrete are many as it is a creative, versatile, economical, and sustainable method for the concrete construction needs ahead.

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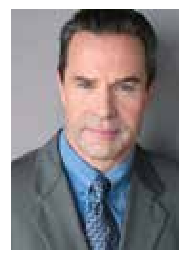

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WORLD OF
CONCRETE

History of ASA

By Scott Rand

Much of the initial credit for the creation of the American Shotcrete Association (ASA) goes to Milt Collins. Collins was managing the International Concrete Repair Institute (ICRI) back in the late 1990s and had been talking about the concept of a trade association for the shotcrete industry for a couple of years. In 1997, he approached George Yoggy and Pete Tatnall with his thoughts, even going to the extent of arranging and financing the first meeting at his own expense. There was terrific interest and the Association was chartered in March 1998 with the mission to "promote shotcrete." The first formal ASA general membership meeting was held later that year, just prior to the 1998 ACI Fall Convention in Los Angeles, CA. The Association's Charter Memberships totaled 76 Corporate and 40 Individual members. Lars Balck was elected as first President and Milt Collins acted as first Executive Director (Collins & Associates).

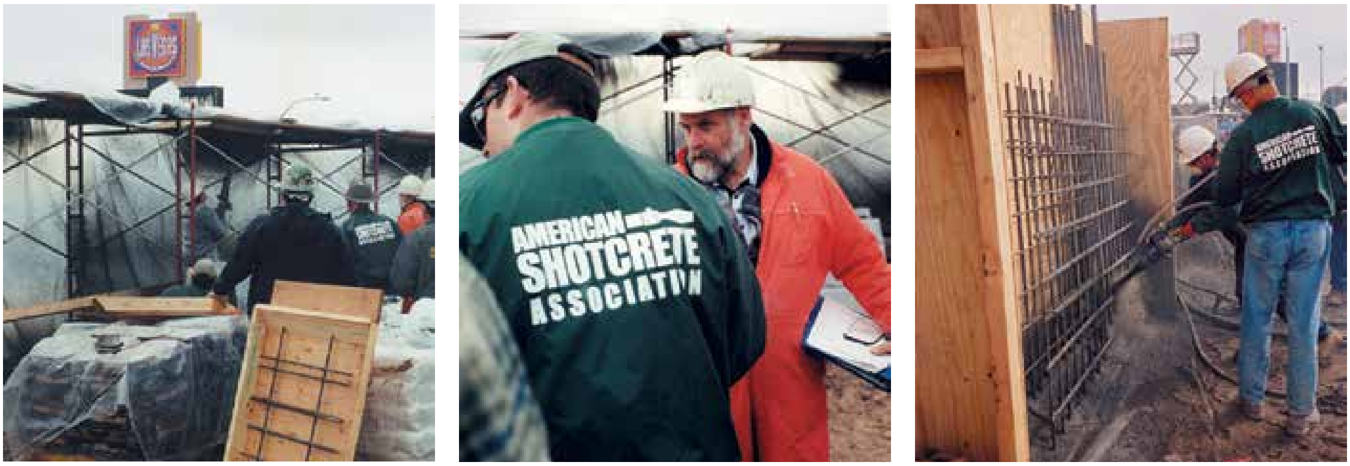
One of the early objectives of the newly organized group was to produce a quarterly magazine. *Shotcrete* magazine was created and in its first year, it won an award for New Magazines and Journals in the APEX 1999 Eleventh Annual Awards for Publication Excellence. Today, *Shotcrete* magazine is distributed around the world and continues to speak directly to that original mission. Beyond its numerous articles, one of the magazine's regular columns is the ASA President's Message. Lars Balck, the Association's first President, took the time to thank a few industry pioneers in his initial memo, namely Ted Crom, Al Litvin, and George Houston Carroll Sr. Twenty years later, there are many more who could be added to that list, including the two gentlemen that Collins originally approached, Yoggy and Tatnall. Another industry notable, Dudley (Rusty) Morgan, quickly became involved and lent tremendous credibility to both the Association and the magazine with his worldwide consulting experience. One of Morgan's earliest pieces discussed the difference between performance and prescriptive specifications. Morgan, in his last Message while President years later (Winter 2008), paid credit to further industry notables, adding to the list above Leon Glasgold, Steve Gebler, Merl Isaak, and Pietro Teichert.

The 1999 Las Vegas World of Concrete meeting was attended by 51 people and interest in the Association was growing. This marked ASA's first year as a pending co-sponsor candidate and our first booth at World of Concrete. By April of that year, the Association had already secured 142 members. The Board of Directors organized five committees to focus on the Association's goals, namely Certification/Education, Marketing, Membership, Publications, and Safety. By August 1999, with membership at 152, planning had started for the first ASA Nozzlemen Certification/Training session in Streetsboro, OH. You may remember that until that point, there was a document that detailed certification procedures (ACI 506.3R, "Guide to Certification of Shotcrete Nozzlemen,") but there was no single group to administer a formal program and give it credibility.

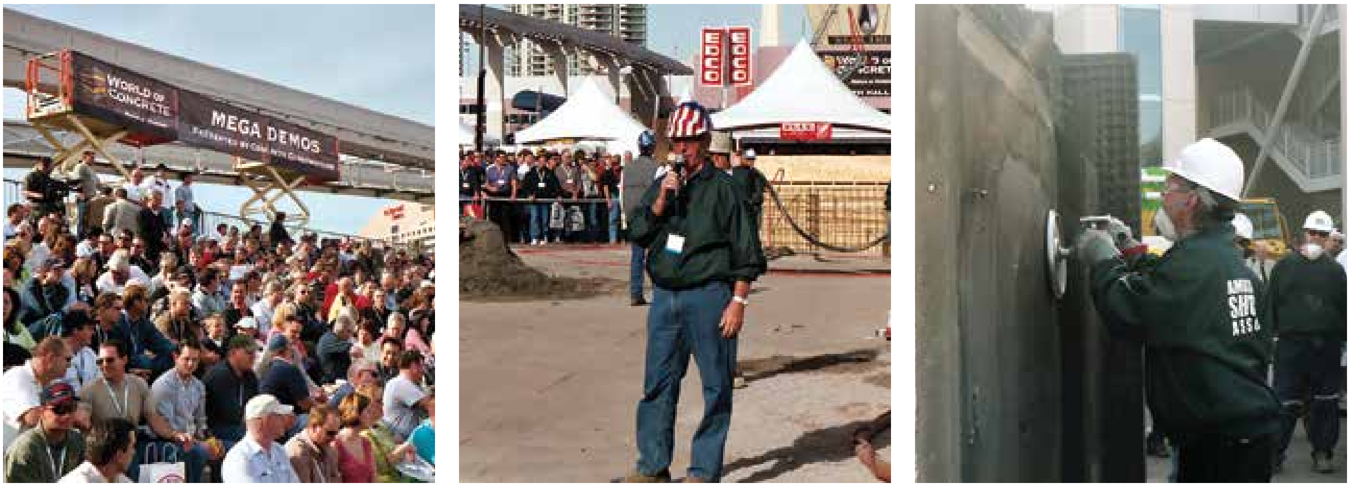
ASA teamed up with ICRI to deliver a joint Concrete Repair seminar at World of Concrete 2000. It was well received by those in attendance and Morgan spoke to the audience about many aspects of the shotcrete process. That seminar marked the first of many presented by the Association during subsequent World of Concrete events. That same year, the Association entered into a management contract with Association Concepts, a for-profit subsidiary of ACI (now known as Creative Association Management) and Rich Heitzmann was named the Executive Director. During that same year, I remember working on the task group that developed the original American Shotcrete Association brochure, first in Quebec City with Marc Jolin, Denis Beaupre, Jean-Francois Dufour, Joe Hutter, and Pete Tatnall, but the finishing touches were truly applied at a follow-up meeting at the ACI offices in Farmington Hills, MI. There, with the help of Marilyn Netter, the day was spent with both Yoggy and Tatnall. Pete told numerous, colorful stories and kept the mood fun while George let us scan through his tremendous historic photo archives. The fact that I can still picture that moment is a testament to both of those fine gentlemen. The year 2000 also brought the development of our website, **www.shotcrete.org**; the formation of the Underground Committee; and the presidency of Tatnall.

World of Concrete 2001 generated more significant advancements. ASA was added officially as a WOC co-sponsor and hosted its first Nozzleman Certification/Mega Demo. Although it takes an army to pull off such a feat, much of the organizational appreciation went to both Yoggy and Chris Zynda. Steve Gentry took over as President and hoped for a greater alliance with the National Spa and Pool Institute. The result was the development of the Pool & Spa Committee.

Shotcrete certification had always been at the heart of the Association. As early as 1994, Heitzmann (then



World of Concrete 2001 ASA Nozzleman Certification/Mega Demo



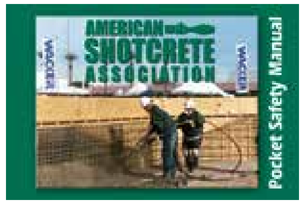
World of Concrete 2005 ASA Mega Demo

heading ACI Certification) helped Lars Balck get ACI Board approval to develop a formal certification program to replace the qualification efforts under the old ACI 506.3R. Activity then seemed dormant until 1997, when John Nehasil became ACI Certification Director and asked CPC member Merlyn Isaak to find out what happened to that initial commission. This resulted in a whirlwind of effort to put a program together, culminating in a pilot ASA certification session in Streetsboro, OH, in September 1999. Another public session took place in Orlando, FL, in April 2000 before the program was turned over to ACI Committee C660, Shotcrete Nozzleman Certification, and the Association became the National Sponsoring Group for the program. ASA then hosted a large public certification session and Mega Demo at World of Concrete 2001, with a total of 12 ACI Shotcrete Nozzleman Certification sessions hosted that year. The certification program started to gain serious momentum!

Ray Schallom III became the fourth President in 2002 and with the ASA Certification program now fully endorsed, the focus became centered on the new 90-minute promotional CD. The hope was that specific disciplines such as Concrete Repair, Civil Tunneling, Mining, Seismic Retrofit, New Construction, Pool & Spa, and Specialty Applications would follow. The Association felt that $50,000 would need to be raised to cover the cost of the professional services. The industry came together at the Burlington, ON, Canada offices of King Packaged Materials Company to undertake the development of this overwhelming task.

In 2003, Ed Brennan focused on developing a formal strategic plan for the Association's future. Meetings were held both at the ACI offices in Farmington Hills, MI, and at the ACI Fall Convention in Boston, MA. The result was a new vision, "that the shotcrete process be understood and used in every beneficial application," and a new mission "to encourage and promote the safe and beneficial use of the shotcrete process." Janice Fisher took over as President in 2004 and Thomas Adams became the new Executive Director.

In front of an estimated crowd of 2500, ASA hosted its second Mega Demo in 2005 at World of Concrete in Las Vegas, NV. Incoming President Larry Totten spoke about the fact that skepticism still surrounded the shotcrete industry despite the recent success and how shotcrete is tested to a level far greater than cast-in-place concrete. Attempting to increase the level of reliability for sodium bentonite waterproofing installations, a meeting was held in July 2005 in San Leandro, CA. The result was to shoot mockups to verify the compatibility of using shotcrete in conjunction with

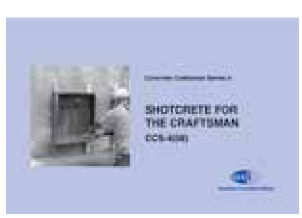


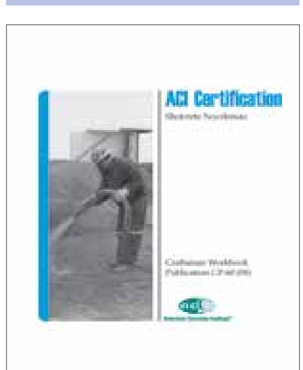
these systems. Safety Committee Chair Zynda was credited for introducing a Pocket Safety Manual, available in both English and Spanish.

During an impromptu meeting in the stands following the 2005 Mega-Demo, Hutter and Brennan first initiated the idea of an ASA's Annual Outstanding Shotcrete Project Awards Banquet. The idea was developed to bring members of the industry together for one night where it could recognize the most outstanding shotcrete projects from the previous year. The Association's inaugural banquet was held at World of Concrete 2006 and the five categories honored were Architectural, Infrastructure, Pool & Recreation, Repair & Rehabilitation, and Underground. The event was attended by 110 people and was an overwhelming success.

Morgan began his two-year term as President in 2006 and in one of his messages spoke to the popular belief that Carl Akeley, inventor of the dry-mix gun, had created it for shooting large frames that were covered with animal skins for museum exhibits. While that practice was true, the real development was for repairing the Field Columbian Museum façade in Chicago, IL. This significant shotcrete industry development was described in great detail in an article written by Teichert in *Shotcrete* magazine's Summer 2002 issue.

The certification program continued to excel and successful nozzlemen now totaled 417 wet-mix and 127 dry-mix, completed by the 10 ACI-approved examiners. ACI's CCS-4, "Shotcrete for the Craftsman," was originally developed, primarily written by Balck, along with Steven Gebler, Merlyn Isaak, Dudley Morgan, and Philip Seabrook. CCS-4 saw a complete revision under the direction of Jean-Francois Dufour and Marc Jolin in 2008. That revision subsequently served as the core material for the ACI Certification Shotcrete Craftsman Workbook, CP-60, that with minor edits still serves as the study material for the nozzleman certification program today. With 32 *Shotcrete* magazine issues and 180 articles to date, the digital archives were becoming a wonderful industry resource and for ease of future access, were added to the website.





A new International category was added to the Annual Project Awards, and joining the President's Award was the newly created Carl Akeley Award in recognition of the 100-year anniversary of his development of the shotcrete gun (1907). In one of his 2008 addresses, new President Zynda spoke of the evolution that he had witnessed over his long career and some of his predictions for the future. He stated that the creativity and versatility of shotcrete contractors should benefit them during these challenging economic times. Chris Darnell took over the responsibility as Executive Director and became a valued part of the executive team.

In 2010, Patrick Bridger, having already spent eight years on the Executive Committee, became the Association's 10th President. Bridger worked together with ICRI and ACPA to further the membership reach. One of Bridger's main objectives was to ask the Education Committee to first analyze and then modify the current procedure and policy for examiners, hosts, and nozzlemen, especially the work experience verification. The committee put forward a recommendation for restructuring, which was fully supported by the Board. Their three main goals were to reduce the administrative work for examiners, allowing them to be objective in their evaluations; standardizing the system as far as costs and timelines to level the playing field; and to create a system of continual evaluation of the ASA Examiners, ultimately making the program more transparent, objective, and consistent. It was a monumental task for the committee who was also working on updating the ASA Educator training module, based on CP-60.

As part of the continuous outreach objective, the Association exhibited for the second time at the International Bridge Conference in Pittsburgh, PA. ASA became one of 27 unified concrete associations in the Concrete Joint Sustainability Initiative to promote the sustainability benefits of concrete. A committee was set up to summarize those benefits specific to shotcrete, chaired by Charles Hanskat. Development also started on the Shotcrete Inspector Education program. In an excellent piece written by Bridger on pre-dampening, he stated that the pros had been well documented since 1922, but still not adopted across the board. They may become more important than ever understanding the U.S. Department of Labor Occupational Safety and Health Administration's new respirable crystalline silica standards.

In 2011, in an effort to appeal to more specifiers, ASA presented at the Midwest Bridge Working Group in Schaumburg, IL. The Association also created and began offering free membership to Employees of Public Authorities/Agencies.

Hutter took over as President at World of Concrete 2012 and while remarking about that year's Awards Banquet, stated that it was perhaps the best to date. The Paris Hotel & Casino provided the finest venues so far, attracting the event's largest attendance, and a record number of projects were submitted, which also helped to secure the greatest number of sponsors to date. The website underwent quite a modification and it was unveiled late in 2012.

Michael Cotter, incoming 2013 President, set out to right the wrong with the Nozzleman Certification program. The unintended circumstances that stemmed from nozzlemen certification was the emphasis placed on the nozzleman, while very little was placed on the qualification of the shotcrete contractor. The Contractor Qualification Committee was developed with the goal of developing a comprehensive program. Mark Campo took over the responsibility as the new Executive Director of ASA.

In 2014, incoming President Hanskat made one of his top priorities to develop a new strategic plan that would guide the Association through the next 5 to 10 years. Hanskat enlisted the help of Jon Hockman, a Washington, DC-based facilitator, and a task group was assembled in Farmington Hills, MI. The group's enthusiastic ideas were written as specific objectives separated into four strategic priorities (Professional Development, Outreach, Credibility, and Organizational Strength). The next step was to sit down with each of the committee Chairs to discuss the division of objectives. In December 2014, the Board unanimously approved the full-time position of Executive Director, to be assumed the first of the year by Hanskat.

Marcus von der Hofen took over the reins as President in 2015 and to further the "Shotcrete is Concrete" education, reestablished the Underground Committee and created a new Technical Committee. Coming out of The ACI Concrete Convention and Exposition – Spring 2015 in Kansas City, MO, it was apparent that the new strategic plan required more focus. The Concrete Convention and Exposition – Fall 2015 in Denver, CO, let the newly formed Strategic Plan task group start the meeting by reviewing all Association committee goals and objectives, achieving consensus not only on what committee should be responsible for each objective but also in which specific priority and by what end date they should be completed. The result was a greater focus and commitment to our next steps. In preparation for World of Concrete 2016, the Marketing Committee unveiled a new logo and updated the entire Association branding at the end of the year.

Bill Drakeley took over as President next and continued to emphasize the importance and accountability of the Strategic Plan scorecard. The Association was realizing tremendous efforts from many groups and the scorecard gave the ability to view all accomplishments or required next steps in one report. Drakeley reminded all members that the only logo you should wear in all meetings is the new ASA one. He also summarized the need for elevated training industry wide, the possible consequences without it, and introduced the NIT program. The Association meetings moved to a dual-track format at The ACI Concrete Convention and Exposition – Spring 2016 in Milwaukee, WI, meetings and worked very well, shortening the common Saturday committee meetings day.

ASA Acknowledges the Contributions and Dedication of our Past Presidents and Executive Directors in shaping the first 20 years of the American Shotcrete Association.

ASA Presidents

1998	Lars Balck
2000	Peter Tatnall
2001	Steve Gentry
2002	Ray Schallom III
2003	Ed Brennan
2004	Janice Fisher
2005	Larry Totten
2006	Rusty Morgan
2007	Rusty Morgan
2008	Chris Zynda
2009	Chris Zynda
2010	Patrick Bridger
2011	Patrick Bridger
2012	Joe Hutter
2013	Michael Cotter
2014	Charles Hanskat
2015	Marcus von der Hofen
2016	Bill Drakely
2017	Scott Rand

Executive Directors

1998	Milt Collins
1999	Richard Storey
2000	Richard Heitzmann
2004	Thomas Adams
2008	Chris Darnell
2013	Mark Campo
2015	Charles Hanskat

AMERICAN SHOTCRETE ASSOCIATION

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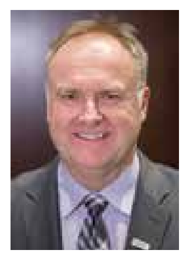
At World of Concrete 2017, Scott Rand took over as President. Rand, managing the Strategic Plan task group, commented that with over 50% of the objectives complete, it was time to write the next chapter of the existing plan. A task group was assembled for a meeting held at the ACI offices prior to The ACI Concrete Convention and Exposition – Spring 2017 in Detroit, MI. One of the ideas that came out of the meeting was to host the Association's 20th Anniversary in Napa, CA, in March 2018. A group of Board members was put together to work on the ASA Shotcrete Convention. ASA will not only host its regular committee meetings and Outstanding Shotcrete Project Awards Banquet at the event but also a technical shotcrete session.

Hanskat is presenting our newly completed Inspector Training Seminar to various Departments of Transportation with the anticipation of a full release early in 2018. The Association will conduct Nozzlemen Certification Education sessions in both English and, for the first time, Spanish at the upcoming 2018 World of Concrete. ASA will also present a seminar on "Advanced Shotcrete: Innovative Techniques for Architectural & Structural Projects" at the Convention.

Today, ASA continues to provide excellent resources to the shotcrete industry. Nozzlemen Certification is quickly approaching the 2000 mark, an incredible achievement. Our Committees are more active and productive within ASA as well as support for ACI 506 activity, and outreach to other standards developing organizations that impact concrete construction. Our reach is more frequently extended beyond the North American borders via certification sessions, association alliances, and more. If shotcrete is your industry, ASA is your resource to grow and develop!

Many people beyond those who have been mentioned in this quick article have had a hand in the success of this Association. While it was not my intention to overlook anyone in the aforementioned summary, there was also an unfortunate realization that more than were mentioned deserve our sincere appreciation. The growth of the ASA programs has required a tremendous amount of support from a long list of outstanding Executive Assistants (Marilyn Netter, Jessie Bournay, and Melissa McClain). This is especially true for current ASA Program Coordinator Alice McComas, whose incredible contribution is essential and much appreciated. To the numerous committee members, especially the Chairs, the various Board members and to the staff behind the scenes working on the magazine, the website, from graphics to logistics...thank you for your contribution over the years.



Scott Rand *is Vice President, Sales, for King Packaged Materials Company, where he is responsible for the Construction Products Group. Rand has over 30 years of experience in the concrete industry and has spent the past 20 years with King. He has had a major contribution in the growth of the King Shotcrete Solutions brand and its leading position in the North American shotcrete industry. Rand has been involved in high-profile projects in numerous cities from New York to Chicago. He is the 2017 President of ASA and a member of ICRI, UCA of SME, CIM, and ACI.*

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INDIVIDUALS

Jason Vickers
Vickers Pools of the Southeast
Birmingham, AL

STUDENTS

Muhammad Ishaq
Rego Park, NY

Mansoor Taj Mohammed
Arlington, TX

INTERESTED IN BECOMING A MEMBER OF ASA?

Read about the benefits of being a member of ASA and find a Membership Application under the ASA Membership tab of www.shotcrete.org.

NEW! ACI 506.6T-17: VISUAL SHOTCRETE CORE QUALITY EVALUATION TECHNOTE

ACI's first Shotcrete TechNote has been released! This is a great companion to the recently released ACI 506R-16. During shotcrete construction, owners, architects, engineers, and contractors want to verify the quality of shotcrete being placed. Shotcrete cores are normally extracted from shotcrete sample panels or when needed from as-placed shotcrete for evaluation of shotcrete quality (ACI 506.4R). In addition to the routine tests such as compressive strength or other material quality tests required by project specification, visual examination of shotcrete cores by an experienced licensed design professional (LDP) is an important tool for evaluation of shotcrete quality.

American Concrete Institute

HAYWARD BAKER EXPANDS ITS REGIONAL PRESENCE WITH NEW OFFICE FACILITIES IN CHARLOTTE, NC

Hayward Baker Inc., North America's leader in geotechnical construction, announced the opening of a new office location in Charlotte, NC. In conjunction with Hayward Baker's existing Greensboro, NC, office, the new Charlotte office supports public, commercial, and industrial clients as well as serving as a resource to the design community addressing challenging geotechnical site conditions.

The new office is located at 6201 Fairview Road, Suite 200, in Charlotte. Gilberto Limon and Alison Savage, PE, are the primary personnel contacts for area customers and can be contacted via phone at (704) 625-2040.

Gilberto Limon will continue to pursue driven piling and deep foundation solutions throughout the region. He received his BS and master's degrees in construction management from Appalachian State University, Boone, NC, and Florida International University, Greater Miami, FL, respectively.

Alison Savage has been active in the geotechnical construction industry for the past decade, holding project engineering and management positions both nationally and internationally. She will work with clients in the Carolinas to develop solutions to complex geotechnical problems. Savage received her BS in civil engineering from Virginia Polytechnic Institute and State University, Blacksburg, VA.

Recent Charlotte-area projects performed by Hayward Baker illustrate the wide range of design-build services the company provides. Among these projects are:

- Encore Southpark—an 11-story multifamily residential project with below-grade parking. The site required ground improvement—specifically, Vibro Piers®—for support of the structure;
- Carolina Panthers Football Stadium upgrades, including new escalators to service the stadium's upper levels, were made possible via Hayward Baker installing driven timber piles through debris-laden fill materials;
- 615 College Street—the installation of 300 high-capacity micropiles provided additional support to an existing below-grade parking deck for the construction of a 12-story structure above while allowing the parking garage to remain open during construction; and
- Bank of America and Ritz-Carlton structures—located at Trade and College Streets, required a temporary excavation support system to depths as much as 70 ft (21 m) below grade for the construction of multiple levels of below-grade parking.

About Hayward Baker Inc.

HAYWARD BAKER
A KELLER COMPANY

Hayward Baker is North America's leader in geotechnical solutions, annually ranked by *Engineering News-Record* (*ENR*) magazine #1 in foundation construction. With a network of local offices across North America, each with direct access to the largest geotechnical knowledge base in the industry, Hayward Baker is ready to respond with the optimal solution wherever the location, whatever the size, whenever required. Solutions include foundation support, settlement control, site improvement, slope stabilization, underpinning, excavation shoring, earth etention, seismic/liquefaction mitigation, groundwater control, and environmental remediation. Learn more at **www.haywardbaker.com**.

Hayward Baker Inc. is part of the connected companies of Keller, a multinational organization providing the optimal geotechnical solution for projects throughout the world. Learn more at **www.keller.com**.

KING SHOTCRETE SOLUTIONS CELEBRATES PLANT EXPANSION IN BRANTFORD, ON, CANADA

King Packaged Materials Company was thrilled to celebrate the successful multi-million-dollar expansion of its operation located in Brantford, ON, Canada. This expansion will afford the King Shotcrete Solutions brand greater operational flexibility when it comes to producing prepackaged dry- and wet-process shotcrete mixtures.

The new addition is the ninth that King has undertaken at this location since it opened the original plant in 1963, and it is the largest expansion to date. The expansion has doubled the original footprint, tripled the capacity, and provided the company with one of the most technologically advanced facilities of its kind in North America.

This type of investment and growth by King speaks volumes in terms of the company's confidence about its future success in both the North American and global marketplace. When the plant is operating at full capacity in the years to come, the company expects to employ a total of 80 to 90 employees in production, quality, and engineering services roles.

The expansion is also an asset when it comes to economic development. "The innovation and competitiveness King brings to the market is what every community hopes to see from its corporate base and we look forward to this company's continued success," says Alison Newton, General Manager of Economic Development and Strategic Investments.

Celebrations at the Grand Opening this September included local dignitaries Mayor Ron Eddy; MPP Dave Levac; and Helen Hillman, Senior Business Advisor at the Ministry of Economic Development and Growth. Mayor Ron Eddy said, "We are pleased to celebrate King's success and wish them a prosperous, long future."

SCHWING AMERICA ACQUIRES ASSETS OF LOOP BELT INDUSTRIES

Schwing America, worldwide designer, manufacturer, and distributor of premium concrete production and handling equipment, announced the closing of transaction for the purchase of all the assets of Loop Belt Industries, makers of high-quality truck-mounted telescopic conveyors.

"We are thrilled to acquire the assets of Loop Belt Industries and incorporate them into the Schwing family," said Bill Murray, CEO of Schwing America. "This asset purchase adds diversification to our existing portfolio and will provide our customers with enhanced high-performance concrete and aggregate conveying options."

The acquisition, which was finalized this September, includes intellectual property, patents, patent applications, copyrights, and trademarks, among other assets. The Loop Belt products include 33 and 40 m (36 and 44 yd) truck-mounted telescopic conveyors, a tractor trailer-mounted 40 m (44 yd) conveyer, and a tower-mounted conveyor for stationary applications.

"The Loop Belt product line complements Schwing's concrete machinery portfolio in a strategic way, enabling our customers to grow with Schwing," said Tom O'Malley, Senior Vice President of Sales & Marketing. "The advanced design features, including an all-tubular steel boom, 20 in. (508 mm) wide belts and flexible outriggers, offer users a reliable unit that can convey several types of materials including concrete, aggregates, and sand."

Along with the asset purchase, Schwing has hired Loop Belt Industries President Joseph Gallione as a Senior Product Engineer & Operations Support Manager. Gallione will continue to lead the Loop Belt product line in its current operating model and the transition of Loop Belt production from Glen Ellyn to Schwing's manufacturing facility in White Bear Lake, MN.

For more information or high-resolution images, contact laudan@linnihanfoy.com.

About Schwing America

Schwing America is part of the Schwing Group, headquartered in Herne, Germany, with plants as well as sales and service centers in several countries. Located in St. Paul, MN, Schwing America manufactures industry-leading concrete pumps, truck mixers, reclaimers, long-reach hydro excavators, and genuine parts for distribution in North and Latin America. Learn more at **http://schwing.com**.

ASA EXHIBITING AT 2017 INTERNATIONAL POOL, SPA, AND PATIO EXPO

ASA will once again be exhibiting at the International Pool, Spa, and Patio (PSP) Expo, October 29-November 3, 2017, in Orlando, FL. ASA Past President Bill Drakeley and Executive Director Charles Hanskat will be conducting an ASA full-day Nozzleman Education Class at the show.

The PSP Expo is North America's largest industry event, covering all segments of pool, spa, and outdoor living. More than 525 manufacturers will be on display, covering 138,000 ft^2 of exhibits. You can also take part in a world-class and unmatched education program targeted to the pool industry. There will also be numerous networking events for you to mingle with industry peers.

The 2017 event will be held in Orlando, FL, at the Orange County Convention Center. With the Orlando International Airport being the third-largest origin and destination airport in the United States, the location makes it convenient for international attendees traveling from over 80 countries. And with the industry thriving in the region, the PSP Expo is a pivotal platform for manufacturers looking to expand their foothold in the Southeast while meeting qualified buyers from across the country and the globe. You can find full information at **www.poolspapatio.com**. Visit the ASA Booth #1162!

WANT TO PROMOTE YOUR COMPANY TO OUR 17,000 READERS?

2018 *Shotcrete* Magazine Media Kit now available!

Advertising in *Shotcrete* magazine is the most affordable and effective way to reach the shotcrete industry. Each issue of *Shotcrete* magazine reaches a growing number of over 17,000 readers that include current and potential designers, specifiers, and purchasers of shotcrete in well over 100 countries.

Themes for 2018 include:

- Winter – Contractors;
- Spring – Outstanding Shotcrete Project Awards;
- Summer – Pools; and
- Fall – Underground.

Your advertisement in *Shotcrete* will reach the companies and people that you need to grow your business. *Shotcrete*'s cost for advertising is competitive, with an average savings of 25% or more compared to other leading trade association magazines. These rates certainly provide you with the most "bang" for your advertising dollars!

For more information including ad rates and deadlines, please download the 2018 Media Kit (**www.shotcrete.org/media/pdf/ASAMediaKit.pdf**). Our streamlined rate charts make choosing the right advertising option for your company easy.

ASA AT 2018 WOC

ASA will exhibit and host educational sessions at World of Concrete 2018 on January 22-26, 2018, at the Las Vegas Convention Center! See the following for highlights of what will be available. Visit **www.shotcrete.org/WOC** for complete details.

Be sure to visit ASA at booth #S10938! Use ASA's source code: A17 for discounted exhibit-only passes.

NOTE: The ASA Outstanding Shotcrete Project Awards Banquet will be held in March at the 20th Anniversary Shotcrete Convention in Napa, CA—see much more information in this issue!

ASA WOC 2018 Committee Meeting

Monday, January 22, 2018, 11:00 a.m.
Las Vegas Convention Center | Las Vegas, NV

ASA Shotcrete Nozzleman Education Class (Course code: ASATU)

Tuesday, January 23, 2018, 9 a.m. – 4 p.m.

This 7-hour program is a requirement for all nozzlemen wishing to pursue certification as an ACI Shotcrete Nozzleman through ASA. However, it also provides a great overview of the shotcrete process for owners, contractors, and project managers.

ASA Shotcrete Nozzleman Education—New Class in Spanish (Course code: ASASTU)

Tuesday, January 23, 2018, 9 a.m. – 4 p.m.

Nuevo en WOC 2018! Este curso está diseñado para el lanzador de concreto, personas involucradas en la inspección del concreto lanzado, y cualquier persona interesada en aprender acerca de los principios y prácticas que se deben de saber y comprender por parte de un lanzador para cumplir con su papel durante una aplicación de calidad del concreto lanzado.

NEW for WOC 2018! CICL Application of Shotcrete Course offered in Spanish—CICL Concreto Lanzado para Reparación y Rehabilitación (Course Code: CICLWE)

Wednesday, January 24, 2018

This course is designed to improve the skills of the nozzleman in the workplace and improve the quality of shotcrete placed. After completing this course, participants will obtain basic knowledge of technology of concrete and shotcrete, including health and safety measures.

Este curso de educación teórica está diseñado para aumentar el conocimiento de todos los involucrados en la reparación mediante la colocación de concreto lanzado. Además de los elementos de la cuadrilla, será útil para contratistas generales, encargados de la construcción, especificadores y propietarios. El objetivo es mejorar la calidad de la colocación del concreto lanzado para la reparación y rehabilitación. Después de completar este curso, los participantes obtendrán conocimientos básicos de tecnología de concreto y concreto lanzado, incluyendo preparación de superficies, selección de materiales y equipos, técnicas de colocación y medidas de seguridad. Los casos de estudios demostrarán cómo aplicar, métodos de diseño, técnicas de colocación y evaluación del control de calidad en estados fresco y endurecido. Ninguna certificación ACI o materiales de estudio del ACI están asociados con esta clase.

ASA 90-minute Shotcrete Seminar: Advanced Shotcrete: Innovative Techniques for Architectural & Structured Projects (Course Code: TH147)

Thursday, January 25, 2018

NEW for WOC 2018! Explore advanced topics and case studies in shotcrete placement for new concrete construction. This seminar will also address building heavily reinforced, thick monolithic concrete sections with multiple layers of shotcrete in addition to a discussion of shotcrete enhanced bond to existing substrates or between newly shotcreted sections.

SAVE THE DATE!

ASA'S First **Shotcrete Convention & Technology Conference** in celebration of ASA's 20th Anniversary is March 11-13, 2018, at the Silverado Resort and Spa in Napa, CA.

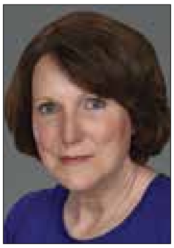
- Full-day Shotcrete Technology Conference;
- ASA Spring Committee meetings (replacing meetings at The ACI Concrete Convention and Exposition – Spring 2018);
- ACI C660 and C601-I Certification Committee meetings (replacing meetings at The ACI Concrete Convention and Exposition – Spring 2018);
- The ASA Annual Outstanding Shotcrete Projects Awards Banquet at nearby Inglenook Winery & Wine Caves (replacing the banquet at World of Concrete 2018); and
- Optional: ASA Contractor Qualification Seminar and program launch.

See many more details in this issue of *Shotcrete* magazine. Hope to see you there!

ACKNOWLEDGMENT OF PHOTOS FROM SUMMER 2017 *SHOTCRETE* MAGAZINE

Jonathan Dongell, author of the "Durability of Shotcrete—Corrosion Protection" article, has provided updated photo credits for the following Figures: 4, 5, 6, 7, and 8. The photos were taken and provided by Greg Musgrove of G & B Tile & Plaster.

ASA WELCOMES BETH HINMAN



Hinman

You may have seen emails or heard a new voice from ASA recently. ASA is pleased to introduce Beth Hinman to the staff, primarily as Editorial Coordinator for *Shotcrete* magazine. With the growing number of programs and activities at ASA, we heartily welcome Beth's assistance to the Association!

WHICH TOPICS IN ASSOCIATION NEWS WOULD YOU LIKE TO SEE IN THIS COLUMN?

Visit **www.shotcrete.org/pages/products-services/shotcrete-magazine-authors.htm**, contact ASA via e-mail at info@shotcrete.org, or call (248) 848-3780 to share your ideas.

Most REED employees have been with the company for decades

REED Shotcrete Equipment has been an ASA Charter Corporate Member since 1999. We thank Reed for their strong support of our Association through continuous membership, event sponsorship, and magazine advertising. Noting that Reed had not yet been featured as a Corporate Member Profile in *Shotcrete* magazine, their recognition in this 20th Anniversary Edition is certainly appropriate.

REED Manufacturing was founded in 1957 by Frank Reed, inventor of the bowl-type dry-mix shotcrete (gunite) machine.

In 1966, John Shea of the J.F. Shea Co. (one of the companies that built the Golden Gate Bridge and the Hoover Dam) was introduced to Reed's revolutionary "guncrete" gunite machines. The units were so effective that Shea Construction used them for all the company's shotcrete work. Shea was so enthusiastic about their performance that he even began selling these guncrete units through one of Shea's distribution companies. In 1970, Shea bought REED Manufacturing from Frank Reed.

REED logo circa 1980s

REED's combination 1-ton Mixer and Shotcrete Pump uses a single power source for both the mixer and the pump. The two machines are connected via "Quick Disconnects," and are separated for easy transport

The M2200 Mixer shown above can also be powered by this small P50 Hydraulic Power Pack instead of the pump

REED then began offering dual-piston swing-tube wet-mix concrete pumps to their guncrete customers in the 1980s through a licensing agreement with Sidewinder International. Shortly thereafter, REED began modifying those designs by making the wet-mix line pumps more powerful and adding additional reinforcement to key components. The first REED-branded wet-mix line pumps were introduced in the mid-1980s.

Today, REED has a state-of-the-art manufacturing facility in Chino, CA, and a worldwide dealer network. REED continues to offer a full line of dry-mix shotcrete machines, as well as some of the most powerful and well-built wet-mix shotcrete pumps and mixers in the market today. REED currently offers 17 different wet-mix pump models, and a wide variety of options from electric drive to fully synchronized chemical dosing systems. Pumps built in REED's factory are custom built to each customer's unique project requirements.

REED pumps and gunite machines are currently at work on jobsites around the world.

REED CONCRETE PUMPS & SHOTCRETE EQUIPMENT

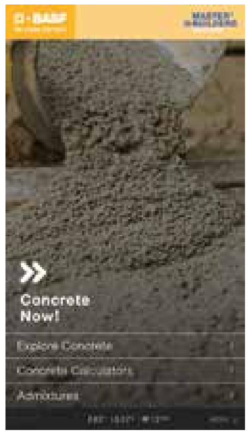
13822 Oaks Avenue, Chino, CA 91710
Phone: (909) 287-2100
www.REEDpumps.com
Mike Newcomb
E-mail: mike.newcomb@reedmfg.com

All REED pumps, gunite machines, and mixers are made in their Chino, CA, factory

REED manufactures their hoppers to extremely precise specifications, so their hopper wear parts last a very long time

BASF LAUNCHES CONCRETE NOW! APP FOR INSTANT ACCESS TO CONCRETE INFORMATION

BASF — We create chemistry



BASF's new and versatile smartphone application, Concrete Now!, is now available in the United States and Canada and allows for instant access to information on concrete properties.

Intended for contractors, engineers, architects, and producers, the free Concrete Now! app serves as a channel to basic knowledge on the fundamentals of concrete use. The app includes items such as concepts and design factors, and interactive tools that provide answers related to concrete slump, air, finishability, and set time.

"Concrete Now! is like having a textbook in the palm of your hand," said Bradley Violetta, Head of Marketing for the Admixture Systems business of BASF's Construction Chemicals. "We want our customers to get the information they need, when they need it, wherever they are. With Concrete Now! on their smartphones, they'll always have access to information about our products and how to use them. We view this app as one more vital tool from BASF Master Builders Solutions® to help make our customers more productive."

Concrete Now! offers the Synthetic Fiber Dosage Wizard, a unique tool that helps determine the type and proper dosage of synthetic fibrillated fibers or macrofibers required to replace small-diameter bars or welded-wire reinforcement (WWR) used as temperature and shrinkage (secondary) reinforcement.

"Fibers are becoming an industry standard for replacing steel for reinforcement," said Dan Vojtko, Product Manager for Admixture Systems. "With the introduction of MasterFiber® MAC 360 FF hybrid fiber, the latest edition to the BASF fiber product family, we've developed key tools, such as the Fiber Dosage Wizard, to help educate the industry on the best usage of macrofiber technology."

The Concrete Now! app's key features include Surface Evaporation Wizard and Concrete Temperature Calculators that help professionals understand the effects of ambient conditions on concrete.

Concrete Now! can be downloaded free from Apple, Google Play, or Windows app stores.

For additional information, please contact Calvinia Fields, Marketing Communications Manager for Admixture Systems, at (216) 839-7022.

TEC SERVICES EXPANDS CAPABILITIES FOR CONCRETE CHEMICAL ANALYSIS

TEC Services — Testing • Engineering • Consulting

Testing, Engineering & Consulting Services, Inc. (TEC Services) has expanded its ISO 17025 laboratory to include analytical chemistry under the direction of Trey McCants, Chemist/Laboratory Manager. TEC's current ISO certification includes ASTM C114, Standard Test Methods for Chemical Analysis of Hydraulic Cement; ASTM C1152, Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete; and ASTM C1218, Standard Test Method for Water-Soluble Chloride in Mortar and Concrete. The lab can analyze cements, fly ash, geologic raw materials, and pozzolanic samples, in addition to metals, plastics, and epoxies.

In addition to routine chemical analysis for quality assurance with assistance from expert staff, TEC can now analyze for unknown materials, possible contaminants, and whole-rock characterization of raw and geological materials, as well as assist in research and new product development. Their lab is fully equipped with a wavelength dispersive

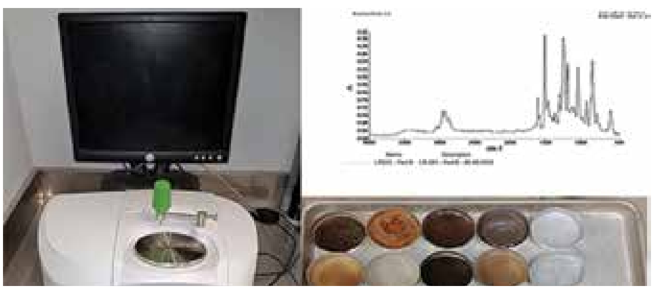
X-ray fluorescence (WD-XRF) instrument capable of analyzing solids, powders, and liquids, in conjunction with fusion and pressed pellet sample preparatory methods.

The optical emission spectrometer (OES) can analyze metal and alloy content of metalliferous products, such as chemical composition of copper, aluminum, and steel.

The Fourier-transform infrared spectrometer (FTIR) allows for high-resolution spectral scans of cements, plastics, admixtures, epoxies, adhesives, and other construction products.

TEC Services, Inc., is located in metropolitan Atlanta, GA, and can be reached through its website, **www.tecservices.com**, or by calling (866) 562-8549.

Optical emission spectrometer



Fourier-transform infrared spectrometer

GCP APPLIED TECHNOLOGIES EXPANDS VERIFI CONCRETE MANAGEMENT SYSTEM THROUGH ACQUISITION OF SENSOCRETE

GCP Applied Technologies Inc. (NYSE: GCP) announced that it has completed the acquisition of all intellectual property and related assets within SensoCrete™, a Canadian technology company in the ready mix concrete industry.

The patented SensoCrete probe technology will augment GCP's successful Verifi® system, which uses sensors installed on concrete trucks to measure, manage, and record concrete properties in transit. Using cloud-based technology, Verifi customers are connected with real-time data that helps to improve the quality and performance of their concrete, increase productivity, and accelerate job completion.

Incorporating SensoCrete technology into the Verifi system will extend the number and type of concrete properties measured. GCP's sensor technologies, construction chemicals, and technical service expertise will offer ready mix customers an even greater range of accurate data, and in turn, significant commercial advantage.

"We pioneered data-driven concrete management in 2010 and have been leading the market ever since. By continuing to invest in our technology, GCP is helping our customers to win through improved quality, performance, and productivity," said Adam Grose, President, GCP Specialty Construction Chemicals. "Now we're expanding our patent portfolio and broadening our technology offering to further enhance our business model and customer value proposition."

"We are witnessing strong demand for Verifi, and we're confident that the incorporation of SensoCrete will further accelerate this trend. GCP provides our customers with unprecedented visibility into their operations and their own delivered product," said Grose.

About GCP Applied Technologies

Through applied knowledge and service excellence, GCP provides premier specialty construction chemicals and specialty building materials for many of the world's most renowned structures, and packaging technologies for the best-known consumer brands, delivering results for all its customers. With customers in 110 countries, operations on six continents, and a team of approximately 2850 employees, GCP had 2015 net sales of US $1.4 billion. Formerly part of the W.R. Grace & Co. group, GCP became a NYSE-listed company (GCP) in February 2016, headquartered in Cambridge, MA.

SHOTCRETE FAQs

As a service to our readers, each issue of *Shotcrete* 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, http://shotcrete.org/pages/products-services/technical-questions.htm.

Question: *We have a client who wants to reline the surface of a brick drying room made from bricks and used to dry bricks. The temperature doesn't exceed 400°F (200°C). Apart from the usual shotcrete best practice, do you recommend the addition of any additives to make the shotcrete/reinforcement more suitable for the heating and cooling cycles?*

Answer: Generally, sand/cement in standard concrete mixtures starts breaking down around 400 to 500°F (200 to 260°C) because the portland cement starts to dehydrate. It loses strength with every phase and will have no strength after 1000°F (540°C). Putting it on brick depends on the shape of the brick surface. Uneven surfaces with holes will hold much better than flat brick. If the brick is flat, placing more than a couple of inches (±50 mm) may delaminate and fall off the wall without anchors of some sort. You could probably use a 2 x 2 in. (50 x 50 mm) or 3 x 3 in. (75 x 75 mm) mesh. In refractory, we consider low temperatures at 1700 to 1800°F (930 to 980°C). In the higher temperature refractory, we use calcium aluminate cement and "traprock," which is a fine crushed limestone aggregate. The mixture ratios would be the same as a typical sand and cement gunning mixture. This is what traditionally has been for coal bunkers and coal dryers or any other sections in the 1700°F (930°C)-plus temperature range.

Question: *Will the new ACI Tech Note for core evaluation (ACI 506.6T-17, "Visual Shotcrete Core Quality Evaluation") replace ACI 506.2-95, "Specification for Shotcrete"? That document has some sections about core evaluation.*

Answer: ACI 506.2-95, "Specification for Shotcrete," is the deprecated version, and is no longer published (it isn't readily available on the ACI website). Thus, the Tech Note along with the current ACI 506.2-13, "Specification for Shotcrete," is the current industry standard for evaluating cores. An engineer may specify use of the outdated ACI 506.2-95; however, they are opening up their exposure because it isn't the current standard. This is similar to the exposure if an engineer uses a much older version of ACI 318, and not the current one.

Question: *We have a question about the shotcrete setup strength for the exclusion zone in underground shotcrete work. New York and others are requiring a shotcrete exclusion zone (an area excluded from personnel) based upon either time or strength. The UK asks for an engineered approach to this minimum strength. Do you have any information on this?*

Answer: The minimum strength for safety must be established by the designer based on the specific structural and geotechnical aspects of the project. The minimum strength value may also be influenced on whether using fiber-reinforced shotcrete or plain shotcrete. The early-age strength was tested with a Meyco Needle Penetrometer after creating a time (early) strength curve with minimum tests at 10 minutes and 30 minutes with Needle Penetrometer; then at 3 hours and 6 hours with Hilti Studs; then at 1, 7, and 28 days with cores. Thus, the curve was calibrated for the specific mixture and environmental conditions. It was also useful to identify when early strength (and potentially long-term strength) was lacking.

Question: *Are there published tolerances for shotcrete, specifically wall thickness, plumbness, and irregularities in surface, or should these tolerances be provided on the construction drawings? ACI 117 provides these tolerances for cast-in-place concrete, but specifically states it does not apply to shotcrete.*

Answer: ACI 117 provides an excellent guide for tolerances for concrete structures. Although shotcrete is concrete, ACI 117 specifically excludes shotcrete because shotcrete's unique method of placement permits a wider variety of applications and uses than that of form-and-pour concrete. Shotcrete can generally be finished to the tolerances required for the application. For example, lining a channel might not need close tolerance control, while an Olympic luge/sledding track or skateboard park may require very exacting tolerances. ACI 506.2-16, "Specification for Shotcrete," in the Tolerances section (and the Mandatory checklist item) requires the specifier producing the contract documents to provide the tolerances required for the project. ACI 506R-16, "Guide to Shotcrete," Section 3.8, Tolerances, provides a more descriptive commentary. Pertinent portions of that section include:

- Tolerances provide an indication of the finished product expected by the owner, but meeting tolerances may require additional effort and cost. Tolerances given by ACI 117.1R, for placement of reinforcing steel, cover over reinforcing steel, and overall alignment of cast-in-place structural members should be generally the same for shotcrete. Tolerances that require distinct values for shotcrete construction are cross-sectional dimensions, cover, and surface finish (or flatness). Therefore, specifying tolerances that can be consistently achieved are needed so that project expectations can be met at a reasonable cost.

- Specified tolerances should be based on use and function and can be the same as concrete, but are typically broader. Some finished surface tolerances may be waived to achieve proper coverage over existing reinforcement.

Although some shotcrete structures have been allowed greater tolerances than allowed for concrete, shotcrete structures can be built to the same degree of accuracy and tolerance as cast-in-place concrete.

You should review the entirety of Section 3.8, Tolerances, in ACI 506R-16 to get a complete description of tolerances for shotcrete placements.

Question: *We are in the swimming pool design and construction industry as a general contractor. We subcontracted a large percentage of the work to complete a project—namely, the shotcrete of the pool shell, and were very unhappy with the results. The walls are not plumb and areas are not shot to the full thickness. We didn't check out the contractor's current work and he is incapable of making any repairs. We have done corrective chipping and bush hammering to get the walls plumb and areas at the proper grade. However, many areas need to be filled to the proper thickness up to 2 in. (50 mm). Can this be done with either a dry or wet mix? Do you need to bush hammer a recessed area to accept a minimum amount of new material in lieu of a feather edge? Is a wet mix acceptable to fill these areas given that the aggregate in it is generally up to 0.375 in. (9.5 mm) or so? With the dry mix being primarily concrete sand and cement it would seem more practical.*

Answer: As you discovered, experience of the shotcrete contractor is key to a successful project. It takes an experienced and knowledgeable shotcrete team (the project manager, supervisor, pump or gun operator, nozzlemen, and finishers) to get a quality job. Answering your specific questions:

1. *Can this be done with either a dry or wet mix?* Yes, either wet or dry mix will produce good results. You must be sure to properly prepare the substrate including chipping/bush hammering back to sound concrete, fully cleaning the surface and then bringing the surface to a saturated surface-dry condition (SSD).
2. *Do you need to bush a recessed area to accept a minimum amount of new material in lieu of a feather edge?* Feather edging will create a very thin layer that would have more potential to spall when exposed to shrinkage or seasonal thermal movements. We recommend creating a square shoulder at least 0.75 in. (19.0 mm) deep to create an acceptable thickness of the patching layer.
3. *Is a wet mix acceptable to fill these areas given that the aggregate in it is generally up to 0.375 in. or so?* With the dry-mix being primarily concrete sand and cement it would seem more practical. Wet-mix with a coarse aggregate can be shot in thin layers, but with a 0.375 in. coarse aggregate may require more finishing due to impact depressions of the aggregate in the shot surface. A dry-mix material without coarse aggregate may be easier to fill in the thin layers. Dry mix is typically less productive in volume placed per hour than wet mix, but in this relatively small-volume repair application, either process should be fine.

Question: *We are a small community in south central Illinois with a deteriorating masonry building issue that drastically needs to be addressed. I have been looking at your shotcrete product and I am thinking that this may be the most efficient and economical way to protect these exposed* *surfaces from the elements and stabilize these structures. My question to you is: Have any other communities used this product for this purpose, can this product be used in a situation such as ours, or am I just barking up the wrong tree? The wall in question is three stories tall, about 40 ft (12 m); the exposed wall was interior multi-course thick masonry from the late-1800s era.*

Answer: Your proposed project is a great application for shotcrete. We've seen shotcrete used for enhancing structural integrity of historic masonry structures across the country. Often shotcrete is used on the back side of the wall to add structural strength while preserving the exterior appearance. In effect, we build a structural concrete wall in-place behind the old wall. Shotcrete has the natural advantage of not requiring any formwork, and can create a good bond to the existing wall, letting the structure elements work together. Here's a link to a past article from *Shotcrete* magazine documenting the restoration of a historic brick building (**www.shotcrete.org/media/Archive/2009Win_SCM01pg08-12.pdf**). If you don't need to preserve the exterior appearance, you can certainly shotcrete the exterior of the wall using the same approach. You can finish the interior (or exterior) surfaces in a variety of ways to provide the architectural appearance you desire. Shotcrete is a placement method for concrete, so using shotcrete will provide a final structure with the strength and durability of cast concrete. By the way, the term "gunite" is the old tradename for what we currently call "dry-mix shotcrete." Let us know if you have any further questions.

Question: *We had a spa added to an existing pool. The shotcrete was too liquid and sloughed off to the bottom. The shotcrete contractor scooped the sloughed material from the bottom with his hands and put it back on the wall. There are fissures and holes in the wall. There was also reinforcing steel close to the surface of the wall. The cold joint at the existing pool wall wasn't prepared. They added a shotcrete seat to the existing pool over the old Marcite with no removal or roughening up of the surface. They then refused to water cure it. There wasn't enough reinforcing steel and formwork from the pool company, so the shotcrete contractor had to stop and add more steel from steel I had lying around. So, the shotcrete sat in the truck for quite a while before shooting.*

We are concerned about the quality of the pool.

Answer: You are correct in suspecting quality issues with your pool. These are the specific issues that lead to poor quality, that can affect the serviceability and durability of your pool.

1. Shotcrete placement requires high velocity and impact for compaction of the concrete. Hand-applying "sloughed-off" concrete would not provide proper compaction needed for producing monolithic concrete sections. The resultant fissures and voids in your pool reflect the lack of proper velocity and compaction.
2. Proper preparation of the substrate is essential for good bond and creating a concrete section that acts monolithically. The surface needs to have any materials that would interfere with the bond removed, be roughened, cleaned, and brought to a saturated surface-dry condition before shotcrete placement. This article from *Shotcrete* magazine gives more details on how and why surface preparation is important (**www.shotcrete.org/media/Archive/2014Spr_TechnicalTip.pdf**).
3. Concrete cover over the reinforcing bar is critical for maintaining corrosion protection of the embedded steel, and thus providing long-term durability. Low cover will often result in premature corrosion and subsequent spalling of the concrete cover, reducing the serviceability and life of the pool concrete.
4. Curing is important for all concrete, and especially for the relatively cement-rich concrete we use for wet-mix shotcrete. Curing essentially provides additional water to hydrate the cement in the concrete, and produces stronger, less permeable concrete. Not curing concrete yields concrete that is weaker, more permeable, and ultimately less suitable for creating a watertight pool shell.
5. You haven't indicated the actual time concrete sat for "a while." Industry standards are that concrete should be placed within 90 minutes of the introduction of water to the mixture unless special precautions are taken. Water is usually added at the ready mix plant. If concrete sits too long it can start to lose workability. At the point of losing workability, some contractors will add additional water on site over and above the concrete mixture design requirements, but this "retempering" produces concrete that is weaker and more permeable than the original design mixture.

Based on your input, you have many good reasons to ask the contractor to provide full remediation of these quality issues.

Question: *We are looking for the application of shotcrete on tidal waters. We are located on Lower Puget sound in Washington state and need examples where this has been used and is holding up under the moving tides.*

The examples don't have to be applied to our area; the same conditions may apply to other saltwater areas.

Answer: Shotcrete is a placement method for high-quality concrete. Here's a link to an article of a rehabilitation of a concrete-supported lighthouse in the Saint Lawrence Seaway (Pointe de la Prairie Lighthouse) that provides a lot of detail on an installation similar to yours, including saltwater exposure in a tidal zone: **www.shotcrete.org/media/Archive/2014Sum_Sustainability.pdf**. Plus, this project also has extreme freezing-and-thawing exposure.

2017 ASA BUYERS GUIDE

The following list of ASA Corporate Members is current as of October 4, 2017. For a current listing, including the ability to search by seven major specialties (as well as over 100 subspecialties) and states/provinces served, visit the online ASA Buyers Guide at **www.Shotcrete.org/BuyersGuide**.

Name/Contact Information		Specialties						
		Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Active Minerals International, LLC	www.acti-gel.com	•	•					
Advanced Shoring & Underpinning Inc.	www.advancedshoring.com				•			
Advanced Shotcrete Inc.	720-283-8888				•			
Airplaco Equipment Company	www.airplaco.com					•		
Alexander Wagner C.o, Inc.	www.awagnerco.com				•	•		
Allison Park Contractors Inc.	www.allisonparkcontractors.com				•			
American Concrete Restorations Inc.	www.americanconcreterestorations.com				•			
American Standard Conc Pumping Hawaii Inc.	www.ascphi.com			•	•	•		
Aqua Gunite Inc.	www.aquagunite.com				•			
Arco Gunite, Inc.	http://arcogunite.com				•			
Arnold Brothers Inc.	www.arnoldbrothers.net		•	•	•		•	•
Artisan Skateparks, Artisan Concrete Services, Artisan Pools NC	252-202-1333	•	•	•	•			•
Associated Pool Builders Inc.	www.associatedpoolbuilders.com				•			
Atlantis Marine Habitats, LLC	www.atlasmarinehabitats.com				•			
Azteca Gunite	www.aztecagunite.com				•			
Basalite Concrete Products – Vancouver ULC	www.basalitedrymix.com	•	•	•			•	•
BASF Admixtures Inc.	www.basf-admixtures.com	•	•					
Bekaert-Maccaferri Underground Solutions	www.bm-underground.com			•	•	•	•	•
BelPacific Excavating & Shoring Ltd.	www.belpacific.com			•	•			
Berkel & Company Contractors Inc.	http://berkelapg.com				•			
The Blanchard Group	www.blanchardgroup.ca							•
Blastcrete Equipment Company	www.blastcrete.com			•		•		
Bojay's Masonry Contracting Inc.	808-982-8283			•	•			
Boulderscape Inc.	www.boulderscape.com				•			
Brayman Construction Corporation	www.brayman.com				•			
Brierley Associates	www.brierleyassociates.com			•				
Buesing Corp.	www.buesingcorp.com			•	•			

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		Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Bulley & Andrews Concrete Restoration	www.bacrllc.com				•			
BVR Construction Company Inc.	www.bvrconstruction.com				•			•
CA Hull Co. Inc.	www.cahull.com				•			•
Cal Gunite	661-589-0556				•			
California Skateparks	www.californiaskateparks.com			•	•			
Canadian Greenfield Technologies Corp.	www.canadiangreenfield.com	•					•	
CanCrete Equipment Ltd.	www.cancreteequipment.ca					•		
Canusa Equipment Ltd.	www.canusaequipment.com					•		
Carolina Concrete Systems, Inc.	www.carolinaconcretesystems.com			•	•			
CCS Group LLC	www.ccsgrouponline.com	•	•	•	•	•	•	•
Cementec Industries Inc.	www.cementec.ca	•	•					
CemenTech Inc.	www.cementech.com	•				•		
Cemrock Landscapes Inc.	www.cemrock.com				•			
Classic Tile & Plaster, LLC	601-372-0164		•	•	•		•	•
Coastal Gunite Construction Company	www.coastalgunite.com				•			
Concrete Frame Associates, LLC	www.concreteframe.com			•	•			
Condon-Johnson & Associates Inc.	206-794-5828				•			
Construction Forms, Inc.	www.conforms.com					•		
Construction Revolution Group	210-620-8776				•			
Contech Services, Inc.	www.contechservices.com				•			
Crom LLC	www.cromcorp.com				•			
Cruz Concrete & Guniting Repair Inc.	732-223-2206				•			
C-TEC, Inc.	www.ctecconcrete.com				•			
CTS Cement Manufacturing Corporation	www.ctscement.com	•	•					•
Custom-Crete	www.custom-crete.com				•	•		•
D Construction Inc.	www.dconstruction.net				•		•	•
Deep Foundations Contractors Inc.	www.deep.ca				•			
Dees-Hennessey Inc.	www.deeshenn.com				•			
Delta Gunite and Shotcrete	702-471-1117			•				•
Delta Gunite Solano Inc.	www.deltagunitesolano.com				•			•
Delta Industrial Services Inc.	www.deltaindustrial.com							•

Name/Contact Information		Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
		Specialties						
Deluxe Shotcrete & Concrete Construction	www.deluxeshotcrete.com			•	•			•
Desert Shotcrete Inc.	520-749-4848				•			
DMB Construction Corp.	631-232-3748				•			
DN Tanks	www.dntanks.com				•			
Dome Technology	www.dometech.com				•			
DOMTEC International LLC	www.domtec.com			•	•			
Drake Inc.	www.drakeinc.net			•	•			
Drakeley Industries LLC	www.drakeleypools.com			•	•			
Drill Tech Drilling & Shoring, Inc.	www.drilltechdrilling.com			•	•			
Eastco Shotcrete, LLC	www.eastcoastshotcrete.com				•			
Eastern Gunite Company Inc.	www.easterngunite.com				•			
Elasto Plastic Concrete	www.elastoplastic.com			•			•	
Engineering & Construction Innovations Inc.	www.EandCI.co				•			
Epoxy Design Systems Inc.	www.epoxydesign.com			•	•			
Era Valdivia Contractors	www.eravaldivia.com				•			
Euclid Chemical Company	www.euclidchemical.com	•	•				•	
Facca Incorporated	www.facca.com				•			
Farr Foundation Inc.	www.farrfoundation.com			•	•			
Fibercon International Inc.	www.fiberconfiber.com				•		•	
Fibermesh® Concrete Solutions by Propex	www.fibermesh.com			•	•		•	
Forta Corporation	www.fortacorp.com						•	
Freyssinet Inc.	www.freyssinetusa.com				•			
Frontier-Kemper Constructors Inc.	www.frontierkemper.com				•			
Gall Zeidler Consultants	www.gzconsultants.com			•	•			
Gary Carlson Equipment Co.	www.garycarlsonequip.com			•		•		
Genesis/NSPF	www.genesis3.com			•	•			
GeoBuild, LLC	www.geobuild.com			•	•			•
Georgia Gunite and Pool Company	http://georgiagunite.com				•			•
Geostabilization International	http://geostabilization.com				•			
Getman Corporation	www.getman.com					•		

Name/Contact Information		Specialties						
		Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Global Specialty Contractors, Inc.	651-406-8232				•			
Graciano Corporation	www.graciano.com				•			
Grindline Skateparks Inc.	www.grindline.com			•	•			
Group Works LLC	www.groupworksllc.com			•	•			
GT Gunite	www.gtgunite.com	•			•			
Gunite Specialists Inc.	www.gunitespecialists.com				•			
Guy F Atkinson Construction	512-483-4682				•			
Harris Rebar	www.harrisrebar.com						•	
Hayward Baker Inc., Craig Olden Division	www.oldeninc.com			•	•			
Hayward Baker Inc.	www.haywardbaker.com				•			
HCM Shotcrete	www.hcmshotcrete.ca				•			
High Country Pools, Inc.	www.highcountrypools.com			•	•			
Hydro Arch	www.hydro-arch.com				•			
J Tortorella Swimming Pools Inc.	www.tortorella.com	•		•	•			•
JC Shotcrete	604-854-5700				•			
JCM Northlink LLC	www.jaydeecontr.com	•	•	•	•			
JE Tomes & Associates	www.jetomes.com	•	•					•
Jetcrete NA	www.thyssenmining.com				•			
John Rohrer Contracting Company Inc.	www.johnrohrercontracting.com				•			
Jones Excavating	http://jonesexcavating.com				•			
KHM Inc.	607-773-0076				•			
KIA Contractors Inc.	www.kiacontractors.com	•		•	•	•		•
Kiewit Infrastructure Co.	201-571-2730				•			
King Shotcrete Solutions	www.kingshotcrete.com					•	•	•
Knowles Industrial Services Corp.	www.knowlesindustrial.com				•			
Kryton International Inc.	www.kryton.com	•						
Lanford Brothers Company Inc.	www.lanfordbrothers.com				•			
Limen Group Const. Ltd.	www.limengroup.com				•			
Lithko Restoration Technologies, LLC	www.lithkorestoration.com				•	•	•	•
LRL Construction Co Inc.	www.lrlconstruction.com			•	•			
Lrutt Contracting Ltd.	www.LRutt.com				•			

Name/Contact Information		Specialties: Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
LS Black Constructors	www.lsblack.com				•			
Madole Construction Co. Inc.	www.madoleconstruction.com				•			
Malcolm Drilling Co. Inc.	206-510-7224				•			
Mapei Corporation	www.utt-mapei.com	•						•
Mar-Allen Concrete Products Inc.	717-859-4921				•			
Matcon Excavation & Shoring Ltd.	www.matcon.ca				•			
Mays Construction Specialties Inc.	www.mays-mcsi.com				•			
McGill Restoration Inc.	www.mcgillrestoration.com				•			
Metro Testing Laboratories (Concrete Restoration) Ltd	www.metrotesting.ca			•	•			
Mid-American Group	734-586-8868				•			
Mid-American Gunite Pools Inc.	www.midamericanpools.com				•			
Mid-West Gunite, LP	314-731-7575			•	•			
Minova Global	www.minovaglobal.com							•
Morrison Engineers PLLC	www.morrisonengineers.com			•	•			
Mosites Construction Company	www.mosites.com				•			
The Nassal Company	www.nassal.com			•	•			
National Gunite	www.nationalgunite.com				•			
National Pools of Roanoke Inc.	www.nationalpools.com				•			
Nationwide Shotcrete Inc.	http://nationwideshotcrete.com			•	•			
New Line Skateparks Inc.	www.newlineskateparks.com			•	•			
New York Concrete Corp.	http://newyorkconcrete.com				•			
NMN Construction	www.nmnconstruction.com				•			
Norcal Pool Construction Inc. dba South Bay Gunite	408-362-9553				•			
Normet Americas Inc.	www.normet.fi/contacts/ region_americas_contacts	•	•	•		•		
Olin Engineering Inc.	www.olinpump.com					•		
Oscar Orduno, Inc.	www.oscarordunoinc.com				•			
Osco Mudjacking & Shotcreting Ltd.	www.mudjacking.com				•			
Palmetto Gunite Construction Company Inc.	www.palmettogunite.com				•			
PCiRoads LLC	www.pciroads.com				•			

Name/Contact Information		Specialties						
		Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
PLI Systems, Inc.	www.plisystems.com				•			
Polycrete Restorations Ltd.	www.polycreterestorations.com			•	•			
Pool Engineering Inc.	www.pooleng.com			•	•			
Precon Marine Inc.	www.preconmarine.com				•			
Preload	www.preload.com				•			
Prestige Concrete Products	www.prestige-gunite.com			•	•			•
Prometheus Construction	www.prometheusconstruction.com				•			
Promiz, LLC	http://cem-mend.com			•	•			•
ProShot Concrete Inc.	www.proshotconcrete.com				•			
Proshot Structures	http://pro-shot.ca				•			
Pullman-Shared Systems Technology, Inc.	www.pullman-services.com				•			
Putzmeister Shotcrete Technology	http://PutzmeisterShotcrete.com					•		
The Quikrete Companies	www.quikrete.comShotcrete		•					•
Quikspray, Inc.	www.quikspray.com					•		
R. W. Haggerty Pool Service Inc.	www.haggertypools.com			•	•	•		
Ralph L Wadsworth Construction Company	www.wadsco.com				•			
Ram Construction Services	www.ramservices.com			•	•			
Ram Jack of Charlotte, LLC	www.ramjackcharlotte.com				•			
R-E-D Industrial Products	www.redindustrialproducts.com	•	•	•				
REED Shotcrete Equipment	www.reedpumps.com					•		
Repcrete Concrete Repairs & Cont. Co.	www.repcreteuae.com				•			
Restek Inc.	www.restekinc.net				•			
Restoration East, LLC	www.restorationeast.com				•			
Revolution Gunite	www.RevolutionGunite.com			•	•			
Riverdale Mills Corp.	www.riverdale.com						•	
Russo Corporation	www.russocorp.com			•	•			
SAK Construction	www.sakcon.com				•			
San Joaquin Gunite	www.sanjoaquingunite.com				•			•
Schnabel Foundation Company	www.schnabel.com				•			
Schwing America, Inc.	www.schwing.com					•		
Selinsky Force	330-477-4527				•			

Name/Contact Information		Specialties: Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Seminole Enterprises	407-834-8091			•	•			•
Shannon & Wilson Inc.	http://shannonwilson.com			•				
Shotcrete Africa SCP (Pty) Ltd.	www.shotcrete.co.za		•	•	•	•	•	•
Shotcrete Auckland Ltd.	011-6421701807	•			•	•	•	•
Shotcrete Contractors Inc.	http://shotcretecontractors.com				•			
Shotcrete Helmet	www.shotcretehelmet.com					•		
Shotcrete Montana	www.shotcretemt.com				•	•	•	•
Shotcrete Structures Inc.	www.shotcreteinc.com			•	•			•
Shotcrete Supply LLC	www.shotcretesupply.com	•	•	•	•	•	•	•
Shotcrete Technologies Inc.	www.shotcretetechnologies.com	•	•	•	•			
Sika Corporation	www.sikaconstruction.com	•	•					
Sika Schweiz AG, Aliva Equipment	www.aliva-equipment.com					•		
Sofis Company Inc.	www.sofiscompany.com			•	•			
South Bay Gunite Company	713-932-6669		•	•	•			•
South Shore Gunite Pools & Spas Inc.	www.ssgpools.com			•	•			
Southwest Contracting Ltd.	www.southwestcontracting.ca				•			
Southwest V-Ditch Inc.	www.swvditch.com				•			
SPB Torkret Ltd.	www.torkret.com.pl			•	•			
Spec Mix Inc.	www.specmix.com		•	•		•	•	•
SpecChem LLC	www.specchemllc.com	•						
Spiniello Companies	www.spiniello.com			•	•			
SprayForce Concrete Services Ltd.	www.sprayforceconcrete.com			•	•			
Stone Valley Construction Services LLC	www.stone-valley.com			•	•			
Strata Mine Services	www.strataworldwide.com				•			
Structural Shotcrete Systems Inc.	www.structuralshotcrete.comindex.html				•			
Structural TOPCOR LLC	www.structural.net			•	•			
StructureWerks	www.structurewerks.com			•	•			
Subsurface Construction Company	www.subsurfaceconstruction.com				•			
Sunshine Construction	415-479-5566				•			
Sunwest Gunite Co.	www.sunwestguniteco.com			•	•			
Superior Gunite	www.shotcrete.com				•			

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		Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Takbeer Enterprises Inc.	646-235-2441	•		•	•	•	•	•
Terra Engineering & Construction Corporation	www.whyterra.com				•			
TerraFirm Construction LLC	614-875-8200				•			
Testing, Engineering & Consulting Services Inc.	www.tecservices.com			•				
Texaloy Foundry Company Inc.	www.texaloy.com					•		
Texan Gunite	512-383-5341		•	•		•		•
Texas Shotcrete Inc.	972-872-1901				•			
Thiessen Team USA Inc.	www.thiessenteam.com	•		•	•	•	•	•
Thorcon Shotcrete & Shoring LLC	www.thorconshotcrete.com		•	•	•			
Top Gun of Virginia Inc.	www.topgungunite.com				•			
Top Shot Concrete Inc.	www.topshotconcrete.com	•	•	•	•	•	•	•
Torrent Shotcrete Structures Ltd.	http://torrentshotcrete.com				•			
Triforce Construction Inc.	714-895-6500				•			
Tri-State Gunite LP	845-406-8122	•	•	•	•	•		•
Truesdell Corporation	www.truesdellcorp.com				•			
Turnstone Construction, Inc.	www.turnstoneconstruction.com				•			
UMA Geotechnical Construction	www.team-uma.com				•			•
US Concrete Products LLC	www.uscproducts.com	•	•					•
Valley Concrete Services	415-378-8178				•			
Vancouver Shotcrete & Shoring Inc.	www.shotcreteshoring.com			•	•			
Wagman Heavy Civil	www.wagman.com			•				
Walker Equipment Company	www.walker-equipment.com					•		•
West Coast Shotcrete	951-227-0423			•	•			•
Western Materials & Design, LLC	www.wmdus.com		•			•		
Western Shotcrete Equipment Inc.	www.wseshotcrete.com					•		
Westport Pools	www.westportpools.com				•			
Whiteside Construction Corporation	www.wesconshotcrete.com				•			
Wildcat Concrete Services Inc.	http://wildcatcompanies.com				•			
William L Watson Company	716-992-3220				•			
Wright Concrete & Construction, Inc.	www.wrightconcrete.com		•	•	•			
Wurster Engineering & Construction	www.wursterinc.com				•			
Xtreme Shotcrete	http://xtremeshotcretema.com				•			

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