Shotcrete MAGAZINE

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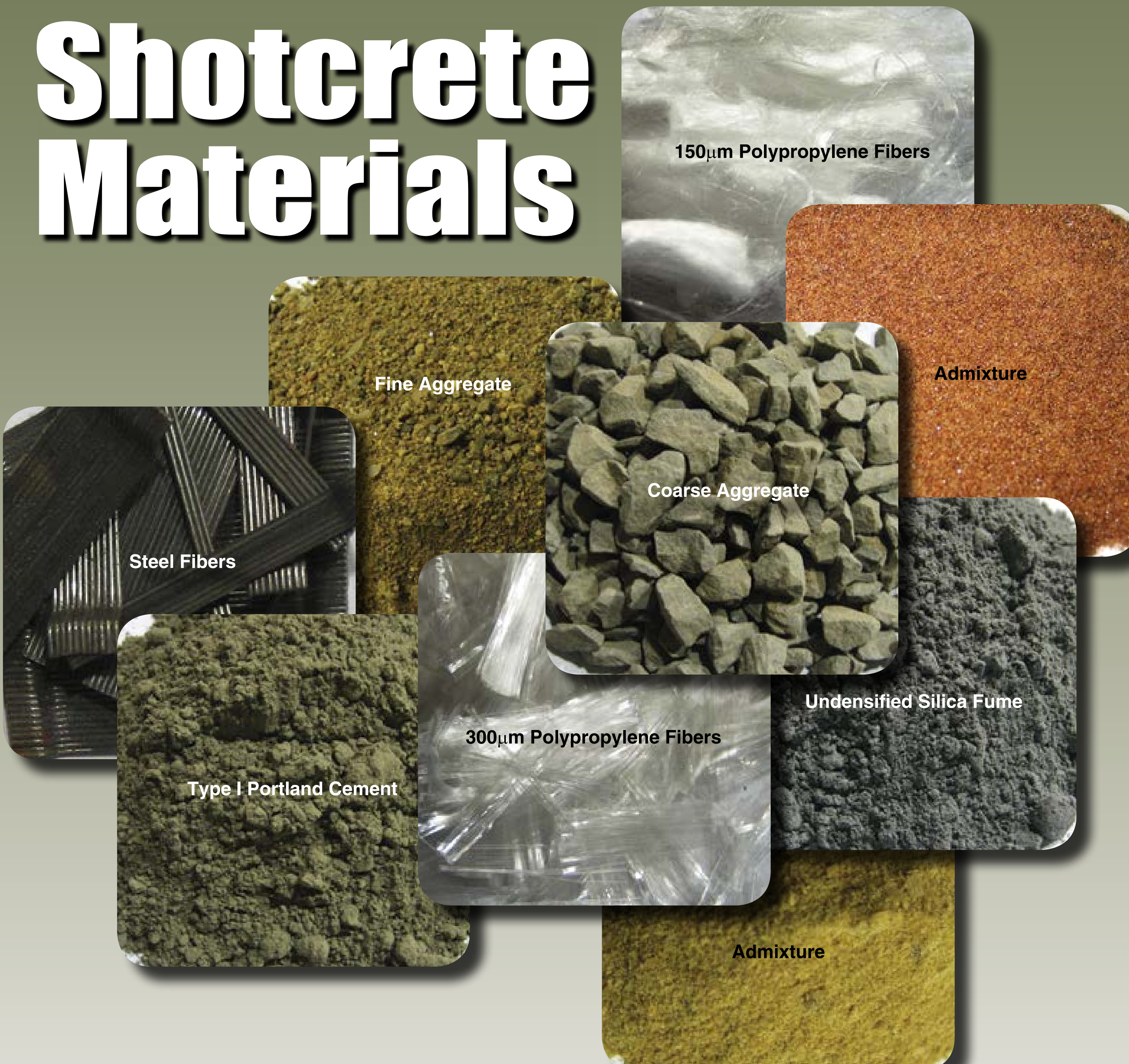
Shotcrete Materials



AMERICAN SHOTCRETE ASSOCIATION

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Volume 15, Number 4
Fall 2013

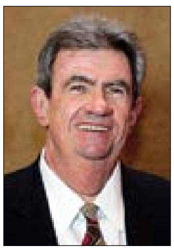
Features

Departments

On the cover: Macro views of typical mixture materials.
Photos courtesy of King Packaged Materials Company, www.kingshotcrete.com.

A Successful Shotcrete Project Starts with the Basics

By Michael P. Cotter



The Qualified Shotcrete Contractor and the ACI Certified Nozzleman should have a minimum of 5 years of experience performing the same type of shotcreting work required for the proposed shotcrete project. At the time of bidding, each contractor should submit an experience list of five projects similar in scope to the current project, showing successful completion. They should ensure that the specified material and the manufacturer's recommended equipment for applying the material will be used, if applicable.

The experience list supplied should contain the following for each of the five previous projects:

- Project name;
- Owner of project;
- General Contractor(s) and Construction Manager (if applicable);
- Owner's representative, address, and telephone number;
- Brief description of work;
- Total cost and duration of shotcreting portion of project;
- Date of completion; and
- Type of equipment used to perform work.

(Refer to ASA's website for further details on the Shotcrete Contractor and Crew Qualifications: **www.shotcrete.org/media/Archive/2013Sum_Hanskat.pdf**)

Recently, I've seen project specifications that require shotcrete to be placed by ACI Certified Shotcrete Nozzlemen, and that is the ONLY qualification for shotcrete on the job. This simplistic specification requirement does not take into account the contractor and trained shotcrete crew's qualifications and experience, but rather emphasizes only having the certified nozzleman. If there is a choice between requiring an experienced shotcrete contractor and trained crew verses just having a certified nozzleman, which job do you think will have the higher success potential? Which job would you want to have your company associated with?

To watch a shotcrete team work is a thing of beauty. It's like looking inside a mechanical watch; every piece, every movement is dependent on another. If you pull a piece out, it doesn't work. It's like listening to a symphony orchestra—the nozzleman being the conductor, and every other member of his crew following his lead working in perfect harmony with each other:

- The gunman or pump operator dispensing a high-quality, consistent mixture;
- The nozzleman fully encapsulating the reinforcing bar and shooting to guides set by the wiremen;
- The hose tender moving hoses and keeping the area around the nozzleman free of hazards;
- The rodmen shaping shotcrete to finish lines;
- The nozzleman assistant operating the blow pipe when required; and
- The finishers applying the final desired finish within an appropriate time without ripping or tearing fresh shotcrete.

My message to you as President is: don't rely on requiring just one part of the system. Airplane pilots don't do it. Captains of ships don't do it. A shotcrete contractor has years of experience and training, along with a significant investment in the shotcrete industry. Their goal is to accomplish a high-quality, long-lasting product that will serve the customer and industry well. That's what you want to buy, not an inexperienced contractor who will hire a certified nozzleman, rent (or maybe buy) minimal shotcrete equipment, mix up a "Betty Crocker" shotcrete mixture, and then call themselves a shotcreter!

The reputations of the finest shotcrete contractors are earned by doing quality work, providing well-maintained equipment appropriate for the type of work, and developing highly trained crews. Using the watch analogy, the nozzleman may be the hands of the watch, but the watch is useless for telling time if the mechanisms inside (the shotcrete crew and equipment) are not in perfect working order, and packaged together by the case (the contractor's business structure) for easy handling. Buy the watch that will best meet your needs!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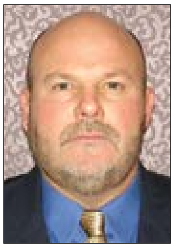
ASA Education Committee

By Raymond Schallom III



It has been awhile since I last reported to ASA's members on the Education Committee's current activities. I am sad to say we lost our Vice Chairman unexpectedly this year. The offer goes out to our membership or committee for anyone willing to become the next Vice Chair. The ASA Education Committee meets at least twice a year in conjunction with the American Concrete Institute's (ACI's) spring and fall conventions. All are invited to attend and become involved in this important ASA function.

The Education Committee has been working hard to update the education modules for the ACI Nozzleman Certification Program. Leading this effort, Oscar Duckworth and his team—Ed Brady (deceased), Marc Jolin, Neil McAskill, and Dudley R. (Rusty) Morgan—have been working diligently to update and improve the ASA education modules to include the most current construction practices and technology. Work with the Pool and Recreational Shotcrete Committee is also ongoing to create a pool module that could perhaps be used in conjunction with the education module during an ACI Nozzleman Certification session or as a standalone education module for the pool industry.

Another subcommittee has worked hard to put together a module for the Inspectors Certification Program for shotcrete. It has been a long uphill battle to convince our membership and ACI that this program is necessary. Great job by our Education Subcommittee whose hard work and dedication is making this possible. A thank-you goes out to the subcommittee responsible for putting it all together: Dan Millette and Oscar Duckworth (Co-Chairs), Ed Brady (deceased), Michael Cotter, Ryan Poole, Ted Sofis, Marcus von der Hofen, Lihe (John) Zhang, Bill Drakeley, Ron Lacher, and Curt White.

Regarding our current President Michael Cotter's efforts on the Contractor Qualification program, the Education Committee had started work on such a program before. Specifications requiring that contractors only needed to have a certified nozzleman on the job were not the intention of the certification program. We all know that one person, especially the nozzleman, is not responsible for the contract or the job after it is completed. In an effort to move this important initiative forward, ASA has set up a Task Group to write up the criteria for a Qualified Contractor. For those who may have forgotten, ASA's Education/Certification Committee spent countless hours writing up the criteria for the Examiners and nozzleman and the education material for the nozzleman, while starting and implementing the Nozzleman Certification Program before ACI became the governing body and ASA the National Sponsoring group in 2001. ASA is making progress with the criteria/guidelines for implementing the Contractor Qualification Program. This is the time for ASA's members to get involved and share their thoughts and ideas to help the Education Committee members draft up an outline, criteria, and the actual Qualification Program.

As I stated earlier, the Education Committee members, some of whom have been active since the startup of ASA, deserve a big round of applause for sharing their wisdom and valuable time putting together educational materials over the years. This core group has volunteered countless hours to update or create new educational material with the intention of making a difference in the industry. The Education Committee currently lists 16 members and one Chair. Considering all the initiatives this group has undertaken and hopes to undertake, we can always use more volunteers and new committee members that would bring fresh ideas and help lighten the current workload. This is your chance to have a say in the current educational material or the new Contractor Qualification Program by sharing your knowledge and work experience. Your input is always welcome; having fresh ideas is what keeps this committee current with industry changes around the world. ASA is also collecting shotcrete specifications from all types of shotcrete projects around the world for wet and dry applications. We ultimately hope to have a reference tool available on the website for every member, along with contractors, engineers, owners, and municipalities who need help in writing their own specification—including how to specify a qualified shotcrete team.

ASA Education Committee

Raymond Schallom III, Chair | RCS Consulting & Construction Co. Inc.

Paul Ampey | Prestige
Lars Balck | The Crom Corporation
Michael Cotter | American Underground Engineering
Oscar Duckworth | Valley Concrete Services
Roberto Guardia | Shannon & Wilson Inc.
Charles Hanskat | Hanskat Consulting Group, LLC
Warren Harrison | WLH Construction Company
Marc Jolin | Laval University
Ron Lacher | Pool Engineering, Inc.
Dan Millette | The Euclid Chemical Company
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Ryan Poole | DOMTEC International LLC
Andrea Scott | Hydro Arch
Ted Sofis | Sofis Company, Inc.
Marcus von der Hofen | Coastal Gunite
Lihe (John) Zhang | LZhang Consulting & Testing Ltd.

ASA at World of Concrete 2014

By Mark A. Campo, ASA Executive Director

Celebrating its 40th annual event this year, World of Concrete (WOC) is the concrete industry's largest international event, providing a critical outreach and educational opportunity for ASA. The diverse collection of attendees, ranging from equipment and material suppliers to contractors, engineers, and specifiers, creates an outstanding forum to efficiently communicate the numerous advantages of placing concrete via the shotcrete process. Over the years, ASA's presence at this show has grown steadily, and the 2014 show will be no exception. As a result, ASA has created a one-stop source for all WOC-related ASA activities. Please see **www.shotcrete.org/pages/news-events/world-of-concrete.htm**.

The following contains a summary of all the activities ASA has planned at WOC 2014.

Registration

If you are involved in the shotcrete industry and think you may attend WOC 2014, please register for the show using ASA's source code: **A17**. In doing so, you will receive a FREE exhibit-only pass *and* discounts on registration for educational sessions, while helping to support ASA at the same time. ASA has been an official co-sponsor of WOC for several years, and each registration made using ASA's **A17** source code results in a rebate to ASA. This is an easy but important way for you to help generate financial support for ASA, enabling its continued mission to grow the shotcrete industry by marketing and educating on the benefits of the shotcrete process. The easiest way to register is to follow the WOC 2014 link on the ASA website at the aforementioned WOC page.

Remember that early-bird registration for ASA's educational programs mentioned in the following paragraphs ends **December 2, 2013**.

ASA Committee Meetings & Annual Membership Meeting

ASA will hold its committee meetings on Monday, January 20, 2014, (the day before the exhibit hall opens). Meetings will be held in the South Convention Hall of the Las Vegas Convention Center, and are free and open to anyone with an interest in shotcrete. (Room locations are not available at the time of printing. Please check ASA's calendar for the latest updates on times and locations: **www.shotcrete.org/pages/news-events/calendar.htm**.)

The ASA Board of Direction meeting will convene at 9:00 a.m. Following that, the **ASA Annual Membership Meeting is scheduled for 11:00 a.m.** This annual meeting, required in the ASA bylaws, will focus on the announcement of ASA's newly elected board members and officers, in addition to highlighting the key initiatives undertaken by the association this year.

ASA's other standing committees—Education, Sustainability, Pool & Recreational Shotcrete, Marketing & Membership, Publications, Safety, and Underground—each meet twice per year, in the spring and fall. All ASA committees will next meet in Reno, NV, on Saturday, March 22, 2014.

ASA Educational Seminar—Shotcrete for Infrastructure and Building Repair, Rehabilitation, and Repurposing

Each year, ASA conducts one or more seminars as part of the WOC education program. This year's seminar, entitled "Shotcrete for Infrastructure and Building Repair, Rehabilitation, and Repurposing," will be presented by ASA Officers Charles Hanskat and Marcus von der Hofen. The seminar will take place from **1:30 p.m. to 3:00 p.m. on Wednesday, January 22, 2014** (Registration Code: WE139).

This seminar will give the owner, design engineer, project specifier, field inspector, specialty subcontractors, and general contractors an overview on how shotcrete can be efficiently and cost-effectively used for structural repair, rehabilitation, and repurposing of concrete buildings and infrastructure. We will provide a basic overview of the shotcrete process and cover the design, specifying, and detailing considerations for shotcrete repairs. Next, we will cover field considerations, including reduced formwork needs and scheduling advantages. We will also discuss achieving quality of shotcrete, addressing field inspection, specific placement techniques, nozzleman certifications, and contractor qualifications. We will wrap up with a discussion on sustainability benefits of shotcrete and a listing of appropriate references and resources on the use of shotcrete for structural concrete repair.

Having completed this program, you should be able to:

1. Identify design, specifying, and detailing considerations when using shotcrete for repair of structural sections;
2. Delineate the field advantages of shotcrete placement for structural concrete repairs;
3. Know the placement techniques, inspection, and contractor qualifications critical to producing quality shotcrete; and

4. Be aware of sustainability of shotcrete compared to cast-in-place concrete, as well as additional references and resources to learn more about shotcrete for structural concrete repair.

This seminar is an outstanding opportunity to learn from two leading ASA experts in the shotcrete industry. We expect this event to fill up fast, so act soon!

ASA Shotcrete Nozzleman Education Session

Scheduled for **Tuesday, January 21, 2014**, from 9:00 a.m. to 4:00 p.m., this session is designed for shotcrete nozzlemen, individuals involved with inspection of shotcrete, and anyone interested in learning about the principles and practices that must be known and understood for a nozzleman to satisfy his role in the quality application of the shotcrete process.

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

CP-60(09), "Craftsman Workbook for ACI Certification of Shotcrete Nozzleman," is included with the session registration fee.

Please note the following important items about this session:

- **Attendance at this session will not result in certification as an ACI Shotcrete Nozzleman**.
- This session will satisfy the education session requirement for a nozzlemen wishing to pursue certification as an ACI Shotcrete Nozzleman through ASA.
- Attendees wishing to pursue ACI Certification will need to arrange for a certification session with ASA separately from this session.
- Attendees will qualify for and receive a complimentary 1-year ASA Nozzleman Membership.

Sign up on or before **December 2, 2013**, to take advantage of the $295.00 event registration fee; after that date, the fee rises to $345.00 (Registration Code: ASATU).

ASA's 9th Annual Outstanding Shotcrete Project Awards Banquet

This year's awards banquet will be held on Tuesday, January 21, 2014, at the New York, New York Hotel and Casino. I hope you will join us at this important event to meet, connect, and network with leaders in the shotcrete industry. Registration and cocktails with hors d'oeuvres begin at 6:00 p.m. Dinner is served at 7:30 p.m., followed immediately by the awards ceremony. A networking reception with cash bar will continue afterwards. Visit **www.shotcrete.org/BanquetReg** to register. Early-bird registration is available until Friday, January 3, 2014.

Awards Sponsorship Opportunities: Sponsoring the ASA Outstanding Project Awards Program is an investment in highlighting and recognizing the exceptional versatility and quality of the shotcrete process to the construction world. Award sponsors receive excellent exposure through this celebrated program. Please consider getting involved this year by sponsoring at one of the following levels:

- "Big Shooter"—$5000;
- Gold—$2500;
- Silver—$1000; or
- Bronze—$500.

More information is available at: **www.shotcrete.org/media/pdf/BanquetSponsorForm.pdf**.

ASA Exhibit Booth: #S10839

This year, ASA's booth will be in an even more high-profile location along the main aisle in South Hall. We are looking forward to attracting more traffic than ever before, with the potential to reach a larger audience of specifiers whose projects would benefit from the advantages of shotcrete.

The ASA exhibit booth is a great place to find printed resources on shotcrete and networking with others in your field. Be sure to pick up some publications, meet with your colleagues using our meeting table and chairs, or just stop by to say "hello!" Don't forget to register today to take full advantage of this unique and important show.

- *Architectural*
- *Infrastructure*
- *International Projects*
- *Pool & Recreational*
- *Rehabilitation & Repair*
- *Underground*

Ninth Annual Outstanding Shotcrete Project Awards Banquet

New York-New York Hotel and Casino

Staten Island Ballroom

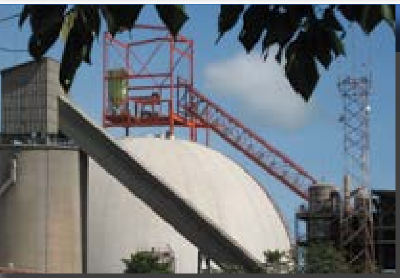
Tuesday, January 21, 2014

6:00-7:30 p.m. Registration, networking, cocktails, and hors d'oeuvres
7:30-11:00 p.m. Plated dinner and awards ceremony
Further networking and cash bar available after the awards ceremony

AMERICAN SHOTCRETE ASSOCIATION

Ninth Annual Outstanding Shotcrete Project Awards Banquet

Registration Form



Join us in celebrating another year of membership success and in recognizing our project award recipients. Submit one form per attendee by January 3, 2014.
We look forward to seeing you in Las Vegas!

Banquet Information:

Location: New York-New York Hotel and Casino, Las Vegas
Staten Island Ballroom

Date: Tuesday, January 21, 2014

6:00-7:30 p.m. Registration, networking, cocktails, and hors d'oeuvres
7:30-11:00 p.m. Plated dinner and awards ceremony, followed by cash bar networking reception.

Attendee Information:

Name ______________________ Company ______________________

Address ____

City ______________ State ______ Zip ________ Country ______________

Phone ______________________ Fax ______________________

E-mail ____

❑ Early bird registration due date: January 3, 2014 ($95-pp)

❑ Pre-registration: January 4-20, 2014 ($150-pp)
Pre-registration before 1/20/2014 is encouraged as only a limited number of seats will be available at the door. (January 21, 2014: $175-pp)
Online registration is now available! Visit **www.shotctete.org/BanquetReg**.

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Limestone Cement in Shotcrete

By Jonathan E. Dongell

Today, the use of supplemental cementitious material (SCM) (fly ash, microsilica, or slag) with portland cement is commonplace. The advantages range from ease of pumping and application to increased rheology and durability. Recently, ultra-fine (micro-fine) limestone "filler" additions, beyond the amounts used as a grinding aid, are being introduced into cements produced in the United States. Many countries allow limestone replacement for certain types of cement. Some countries allow as much as 35% replacement for "general purpose" cement.[1] Replacing a portion of the cement with limestone fines produces a more energy-efficient product and lessens greenhouse gases, but the challenge is to do so "while succeeding in maintaining the fundamental characteristics of hydraulic cement."[2] Perhaps a better goal is to do so while maintaining or improving the fundamental characteristics of the "parent" portland cement; in other words, producing cement that is "green" without sacrificing the performance, characteristics, and durability of the "parent" cement.

In the United States, several ASTM Standards,[3-5] ACI Codes,[6,7] and guides regulate the composition of limestone fines and its usage in concrete mixture designs. However, current ASTM Standards do not require that limestone fineness be fine enough to ensure a similar performance to that of the "parent" portland cement (or "optimizing" the fineness). Instead, current standards focus on requiring a minimum strength, which is designed to ensure that limestone cement performs its primary function as a hydraulic cement binder. Limestone additions that are not "optimized," or ground finer as the limestone replacement increases, can increase permeability and sorptivity, reduce abrasion resistance, and have a higher water demand; thus, producing an overall loss in durability when compared to using portland cement alone.[8-12]

It seems logical that if "optimizing" fineness is an essential factor in producing limestone cement with similar or equivalent properties to the parent portland cement, more stringent fineness requirements should be mandated. Exceptions to the optimized fineness requirement could be made for tertiary blends or blended cements that incorporate combinations of pozzolan and limestone filler, or where an equivalent performance can be demonstrated. Unfortunately, existing standards and codes do not provide specific requirements for this essential aspect of limestone fillers added to portland cement. Until they do, shotcrete companies should consider the following information.

Cement companies cannot be expected to produce cement that is ideal for every usage. For shotcrete, the applicator must ensure that the concrete mixtures with limestone cement produce the specific characteristics and properties of the in-place material that provides the required serviceability and durability in the service environment. It is recommended that prior to using limestone cements in the field, various mixture designs incorporating limestone cement be produced for lab testing. These should then be shot on a number of test panels to ensure the mixture produces an acceptable end product and to familiarize the field crew with the unique material characteristics and workability traits.

Use in Dry, Nonaggressive Exposures

There are significant advantages and disadvantages that should be considered when using limestone cement in relatively dry exposures. In general, increased amounts of optimized micro-fine limestone—up to 15% replacement of the cement—have been shown to slightly improve certain characteristics and properties of portland cement, including increased rheological performance (pumping, placing, and finishing ability); decreased water demand; and decreased drying shrinkage. Therefore, a shotcrete placement where

Table 1: Current allowable limestone limits in cement

Current cement standard specifications	Maximum Allowable
ASTM C150	Up to 5%
ASTM C595	From 5 to 15%
ASTM C1157	No limits

little to no moisture will be present during service life, or where only a mild threat of a chemical-attack environment exists, limestone "filler" replacements up to 15% appear to be acceptable. Again, this assumes that the portland cement and limestone combination has been "optimized."

This increased durability, in which little to no water contact or only mild chemical attack is likely, is due to the fact that increasing the amount of limestone "filler" decreases the amount of cement, which, in turn, decreases the amount of calcium hydroxide normally created as cement hydrates. As the amount of calcium hydroxide decreases, chemical deterioration associated with calcium hydroxide decreases. And, while calcium carbonate formed with limestone cements is also vulnerable to certain water-contact and chemical-attack environments, it is less vulnerable than calcium hydroxide. Secondly, micro-fine limestone has been shown to densify the paste matrix (particle packing), reduce the gap—or distance between—the cement compounds and sand/aggregate (the interfacial zone), and interact with the calcium aluminate component of cement early on to form carboaluminates, which are more stable in dry, nonaggressive environments.[1,8-15]

Overall rheology (pumping, placing, and finishing ability) and workability of the material can be significantly enhanced using optimized micro-fine limestone additions, which are reported to decrease bleed, increase the adhesion of the material to the substrate, and increase cohesion of the material itself. However, the opposite affect can occur as limestone fines increase in coarseness greater than 45 microns (325 mesh). It is also significant to note that while certain workability characteristics may improve using coarser limestone fines, in general, overall durability decreases.[1,8,9,11,12,14]

Use in Wet, Chemically Aggressive Exposures

When shotcrete is placed in a constant moisture/water contact environment, or where a moderate to severe chemical attack environment exists, the overall durability of cement with limestone "filler" decreases with the increase in limestone (calcium carbonate). In such environments, the combination of calcium hydroxide and calcium carbonate becomes more susceptible to attack, and accelerated deterioration of the concrete surface exposed to such conditions is reported. Limestone additions should not be allowed where the potential for sulfate attack (as is common in wastewater treatment facilities or high sulfate soils), accelerated chloride intrusion, or corrosion of reinforcement is a potential risk. Therefore, in shotcrete structures with constant moisture/water contact or where a moderate to severe chemical attack is likely to exist, the addition of limestone "filler" above 5% is not recommended.

Finally, as a helpful guideline, several studies reported a correlation between the fineness of the cement and limestone filler based on the amount of limestone replacement. Based on these reports, it is suggested that the current accepted fineness requirement of bulk fineness of under 45 microns (approximately 325 sieve or 3000 Blaine) and finer is not alone sufficient

Table 2: Compression Strength of Market-Available White Portland Cement vs. White Limestone Cement

Sample I.D.	Type	Date	*w/cm* ratio	7-day	28-day	90-day
White cement 'A', in.	2 x 2 cube	28-Aug-09	0.50 (s)	6181	7765	n/t
White cement 'B', in.	2 x 2 cube	28-Aug-09	0.48 (s)	6529	8328	n/t
White cement 'A', in.	2 x 2 cube	26-Oct-09	0.48 (s)	6333	8143	8455
White cement 'D', in.	2 x 2 cube	26-Oct-09	0.47 (lab)	6436	9879	10116
White cement 'D', in.	2 x 2 cube	28-Aug-09	0.52 (s)	6273	7838	n/t
White cement 'D', in.	2 x 2 cube	10-Aug-10	0.54 (s)	6018	8275	8595
White cement 'A', in. with 15% limestone	2 x 2 cube	12-Jun-12	0.58 (s)	4374	5435	6096
White cement 'A', in. ('parent' cement)	2 x 2 cube	12-Jun-12	0.52 (s)	5614	6240	8211
White cement 'E', in.	2 x 2 cube	6-Sep-12	0.52 (s)	6791	7826	8499
White cement 'D', in.	2 x 2 cube	28-Aug-13	0.52 (s)	7204	9026	r/p
Whie cement 'B', in. ('parent' cement)	2 x 2 cube	27-Aug-13	0.49 (s)	6234	9936	r/p
White cement 'A', in.	2 x 2 cube	28-Aug-13	0.54 (s)	6706	8556	r/p
White cement 'B', in. with 10% limestone	2 x 2 cube	28-Aug-13	0.52 (s)	5064	9301	r/p
White cement 'F', in.	2 x 2 cube	27-Aug-13	0.54 (s)	5506	9184	r/p

Note: n/t is not tested; (s) is field versus lab *w/c*; r/p is results pending

Table 3: Rough fineness conversions for cement

Micron	Mesh	Blaine
74	200	2000
44	325	3000
37	400	3350
30	600	3600
25	710	4000
14	1410	5400
7	—	7800

Note: Some of the references in this paper refer to Blaine fineness and some refer to direct particle size analysis. This table is provided to allow a rough comparison to be made between the two methods of reporting fineness. The Blaine Fineness does not directly correlate to micron or mesh fineness.

to produce limestone cements with equal properties to portland cement. A preferable bulk fineness range for the limestone fillers to produce a limestone cement that is comparable to the "parent" cement would be 30 microns (approximately 600 sieve or 3600 Blaine) and finer for 10% limestone replacement and 15 microns (approximately1450 sieve or 5400 Blaine) and finer for 15% limestone replacement.[1,14,16,17]

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The Use of Recycled Glass in Shotcrete

By Isabelle Fily-Paré and Dr. Marc Jolin

Right after the G8 summit in Japan 2008, the International Energy Agency was mandated to work on the development of technology roadmaps meant to identify specific industries and help governments in their quest for sustainable development. The concrete—or more precisely, the cement—industry was identified as an area with high improvement potential. Indeed, cement production is responsible for about 5% of the total CO_2 emitted in the atmosphere around the globe.[1] The reduction of those emissions is not a simple challenge; the cement production process involves both high melting temperatures (2500°F [1400°C]) and the decarbonation of the raw material (such as limestone), each of which is responsible for about half of the greenhouse gas production. The end result is that for each ton of cement produced, almost a ton of CO_2 is also generated.

This leaves us with two simple approaches for reducing the carbon footprint of concrete construction: either modify the cement production process (a task cement producers are actively working on) or, more simply for the end-user, reduce the amount of cement in concrete mixtures.

Food for Thought

Fortunately, brilliant initiatives for partial cement replacement have found success in recent years. It is interesting to see how concrete became a solution for the disposal of many industrial byproducts, such as slag, fly ash, and silica fume. Once costly material to dispose of, these supplementary cementing materials (SCMs) are now regularly included in concrete mixture designs. Their effects on concrete and shotcrete properties, both in fresh and hardened states, are considered very positive. Consequently, many cement producers around the world are now offering preblended binary or even ternary cements.

Fig. 1: Centre for Sustainable Development, Montreal (www.maisondeveloppementdurable.org/batiment/choix-ecologique-materiaux)

Naturally, the question is whether or not there are other materials that can be used as cement replacement. A plentiful supply of recycled glass, an environmental issue by itself, has attracted the attention of researchers[2-6] around the world. Published results are very promising, including compressive strength improvement, enhanced durability of certain types of mixtures, and even a water-reducing effect in some cases.

Recycled Glass

The recycling of glass is not as simple as it sounds. It is quite unpopular because of the high costs of transportation and the need to sort the different colors. It is unfortunately often cheaper for cities to send glass waste to landfills instead of paying recycling companies to reinsert it in the consumption loop. As an example, in North America, only 33% of the glass used for glass containers is recycled.[7] Even when glass is collected by a traditional recycling truck, only 40% of the collected glass is recycled.[8] Overall, roughly 13% of glass is truly recycled and the other 87% goes to landfills, even though it would be suitable for a second life. While it may not seem cost-effective to recycle glass, wasting it represents a real problem. In China, for example, the government is considering legislation to make glass recycling mandatory because "glass accounts for 3% of all waste in the cities, and only 5% of it is recycled."[9] The same worries are heard across Europe[10] and Asia.

The Use of Recycled Glass in Concrete

The first trials with recycled glass used it as an aggregate replacement. This approach was highly appreciated by architects because of the special final aspect of the concrete produced. Unfortunately, when glass is crushed in particles larger than 75 µm, it induces alkali silicate reaction (ASR) in concrete.[11] The ASR, often-called “concrete cancer,” results in the creation of an expansive (swelling) gel that produces internal cracking in the aggregates and the hardened cement paste matrix. Concrete suffering from ASR exhibits reduced mechanical strength and often severe cracking, which can contribute to accelerated corrosion of embedded steel reinforcement.

Luckily, when the recycled glass is ground into finer particles, it does not create ASR (some studies even suggest that ASR is reduced in the presence of reactive aggregates[12]). Even better, studies have shown that glass powder exhibits pozzolanic activity in which it reacts to form a higher-quality (densified) hydrated cement matrix. Some cases have even shown improved compressive strengths.[2]

Other encouraging studies revealed that glass powder enhances the properties of concrete consisting of fly ash or silica fume. The compressive strengths are higher when glass powder is used with silica fume than when silica fume is used alone.[2] Similar observations have been reported for concrete made with fly ash and glass powder; in this later case, durability was also noticeably enhanced.[13]

Finally, another interesting effect is the water-reducing effect produced when using glass powder. Indeed, despite the high surface area of the glass powder, its surface properties are such that it does not attract water in fresh concrete, leaving more water available for improved workability.[14]

In real life, visionaries have already accepted partial replacement of cement by glass powder. In Montreal, QC, Canada, the designers of the Centre of Sustainable Development have used glass powder for some of their building’s concrete. Using this approach helped the building reach a LEED® Platinum certification.[15] The double impact of diminishing the amount of cement in the concrete and avoiding dumping the glass in a landfill has an important impact on sustainability throughout the concrete industry in Canada.

The Use of Recycled Glass in Shotcrete

With its obvious potential, the use of glass powder in shotcrete appears to be an extremely interesting avenue of research. Unfortunately, there are absolutely no studies available about the effect of glass powder in either dry- or wet-mix shotcrete. This subject is, therefore, the focus of a study recently undertaken in the Shotcrete Laboratory at Laval University in Québec City, QC, Canada. In this study, various levels of cement replacement with glass powder (with and without silica fume) are to be evaluated in both shotcrete processes.

Obviously, the hardened shotcrete properties will be evaluated and compared to reference mixtures. However, it is in the placement phase that the effect of the glass powder may have particularly interesting effects, and parameters such as rebound, reinforcing bar encapsulation, and build-up thickness will be evaluated. Early results obtained on dry-mix shotcrete offered some very interesting behavior during the placement phase. It appears that there is a positive effect on rebound reduction and, more importantly, an improved potential for the mixture to encapsulate large reinforcing bars or obstacles. Researchers and industrial partners alike are eager to see more results from this project in the coming months.

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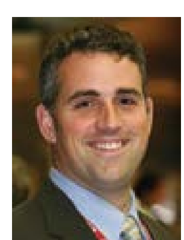

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Volumetric Batching of Wet-Mix Shotcrete

By Mason Guarino

For decades, volumetric batching has been commonplace in the dry-mix shotcrete process. Everyone that has experience with it knows it is fairly easy, convenient, and reliable and allows for ultimate material control. Maintaining the trucks and equipment can be costly, but the expenses are easily covered by the less-expensive material, less wasted material, and any downtime or frustration with ready-mix companies. South Shore Gunite Pools & Spas, Inc. (SSG), has been using volumetric batch trucks since 2000 in the dry-mix process, so when SSG decided to venture into the wet-mix industry, it seemed like a no-brainer, as we already had a volumetric batch plant capable of producing concrete for the wet-mix process. After some trial and error and research, we were able to successfully produce wet-mix shotcrete material with our volumetric batch plant, place it into our pump, shoot it into place, and achieve compressive strengths of up to 6000 psi (41 MPa) in 28 days.

Selecting the Proper Volumetric Batching Machine

When making wet-mix shotcrete material with a volumetric batch plant, you first need to determine your desired expectations of the machine. Some questions you should ask yourself are: How fast do you want to produce wet-mix material? What is your desired mixture design? How do you want to control the water and admixtures? Do you want to set up a silo and machinery for continuous batching or do you want to run back and forth to reload the batch plant? All of these are important factors in determining the type of machinery that will live up to your expectations. I will also address how we use our machinery, calibrating the machine, and some of the advantages over conventional ready mixed concrete. Once started, we learned a lot about what our machine was and was not capable of. We had to modify certain things to get it to run the way we would have liked it to run right from the factory. These things could have been avoided if I had known what to discuss with the manufacturer beforehand.

Volumetric batch plants are often marketed by production rate per hour in cubic yards or cubic yards per hour (yd^3/h). However, their marketing of yd^3/h is based on a much different mixture design than that of a normal shotcrete mixture design. Their yd^3/h is based on a mixture design with less cement and a higher slump. This means that if you want to be able to batch at a speed of 20 yd^3/h (15 m^3/h), you will need to have a more in-depth conversation with the manufacturer. I have found that aiming for batching at 20 yd^3/h works best and gives you options to adjust speed by starting and stopping. Many batch plants are advertising their per-hour rate with a 5.5 cement bag mixture. Wet-mix shotcrete more commonly has an 8 bag or higher per cubic yard mixture. This is easy to overcome by letting the manufacturer know that you need more cement delivered faster than the standard model provides. You may want to specify a little higher rate than your standard mixture so there is an option to increase production. Additionally, the mix auger is typically sized to accommodate a 5 to 6 in. (125 to 150 mm) slump material. With shotcrete, we are commonly looking for a 2 to 4 in. (50 to 100 mm) slump, so the mix auger will need to have more power than provided in a smaller stock machine. Larger stock machines may have sufficient power to handle the lower slumps, but it should be discussed with the manufacturer before you find yourself unable to mix and convey your thicker shotcrete material to the pump. If you plan to run a large truck-mounted volumetric batch machine, this will typically have plenty of power to get the job done. Smaller and stand-alone rigs may not have the necessary power out of the factory.

Mixture Design and Batching Considerations

Mixture designs for volumetric batch plants are not the same as ready mixed, plant-batched mixture designs. A volumetric batch plant typically has some limitations. Some of the limitations I have found relate directly to two of the more favorable additives we use in wet-mix shotcrete: fly ash and mid- to high-range water reducer/plasticizers.

We have found producing a shotcrete mixture with fly ash is currently unfeasible. There are three ways to enable running a fly ash mixture, but they are either not available or very expensive. One way would be to have a supplier blend it for you, but I have not been able to find a supplier in the northeast that will do that for us. The next way would be to run two different powder hoppers on the batch machine, one for cement and one for fly ash. The third way would be to self-blend it before placing the material in the hopper. As a result, we do not currently have the option of using fly ash in our mixture. Since we do not have fly ash, we just use a straight cement mixture.

The specific water reducer/plasticizer considered for a shotcrete mixture needs to be researched. Sometimes a technical data sheet will have all the information, but other times, you may need to get in contact with the manufacturer. Some water reducers/plasticizers require several minutes of mix time, but with a volumetric batch plant, the mix time is under 30 seconds, and that is generous. With some of the plasticizers that take time to react in the mixture, the mixture will look thick with a low slump at the pump. However, as the mixture travels through the hose, the water reducer will start to activate, and by the time it gets to the nozzle, the slump will be undesirably higher. Make sure all of the admixtures can start working quickly with very little mixing time; otherwise, you will just be wasting money and potentially hindering the final shot material. As long as all the admixtures in the mixture can handle a short mixing time, the dosage amounts can typically be kept about the same as a ready-mix design.

Accurate control of water and admixture is very important with a volumetric batch plant. Adding a few gallons to a ready-mix truck to get the mixture where you want it may be okay if the required water-cement ratio (*w/c*) is not exceeded, but always be careful not to go over, or you will potentially ruin the entire batch in the truck and render the concrete unusable. Onsite batching has some advantages over ready-mixed concrete regarding the control of water in the concrete. First of all, the volumetric machine should be equipped with a flow meter that has a flow control unit installed at a location that is easily accessible by the operator (refer to Fig. 1). An extra gallon (4 L) in a 7 yd^3 (5 m^3) truck won't do much to the mixture, but if your water flow is high by 1 gal. (4 L) per minute, that is adding an extra 3 gal./yd^3 (15 L/m^3) of material based on a 20 yd^3/h (15 m^3/h) material rate. Having a good flow meter with easily accessible adjustment allows accurate and consistent control of the water. After calibrating the batch plant, I can determine how much water is acceptable in the material. With that information, I can give the operator a maximum water flow rate, so that as long as he stays under that number, I know the *w/c* will be adequate.

Similar to the water, a little too much admixture can be highly detrimental to the concrete. Our batch plant was originally designed to dilute admixtures into the water and then pump the water into the mixture. We found it difficult to keep up with constantly mixing the proper amount of admixture in mix water because of our continuous batch methods. We also found the standard admixture pumps were not as consistent as we would have hoped. Most likely, volumetric batch plant suppliers offer highly accurate pumps, but we ended up custom-fitting our machine with swimming pool chemical pumps. These pumps have variable frequency drives, allowing us to adjust them based on our needs, and they are incredibly accurate. I have found that monitoring them is unnecessary because once they are set, the accuracy doesn't change. However, I will check—and sometimes recalibrate—the flow if there are substantial temperature changes during the day.

Calibrating the Batch Plant

We require calibrating the batch plant at the beginning of each job. Our typical job lasts at least 3 days. Perhaps the machine could be trusted to maintain all the adjustments and settings throughout the last job and during transport between jobs. However, recalibration at the beginning of the job will also give you an opportunity to re-check everything, and you may find a new issue with the machine or that a valve or gate got moved and does not seat itself the same way. The manufacturer provides a list of steps for calibrating the machines. Our method could be a little different than other users' methods, so I will not go into depth on the entire process, but will highlight some of the important things. The manufacturer should supply an Excel spreadsheet that will allow you to take measurements from the machine, plug them into the sheet, and then tell you how to calibrate for proper supply of sand, stone, cement, water, and admixtures based on your mixture design. Volumetric batch plants have a tendency to be a little inconsistent at times if mistakes are made or assumptions are taken in the calibration process. I always diligently follow the manufacturer's guidelines for calibrating the machine and have had great results.

Setting the conveyor belt speed is an important step because it will set the pace of your job. Too slow and the job will take too long; too fast and

Fig. 1: Flow control flow meter

you will drive the operator crazy by having to shut down the machine too often. Setting the correct belt speed is something you will learn over time with some trial and error. I find that we shoot most walls and thin surfaces slower than we shoot floors and thick walls, so I adjust the belt speed slightly to meet the production rate the application requires. It makes it easier for the operator if he doesn't have to stop and start the batch plant to keep the pump hopper from overflowing. Never adjust conveyor speed mid-job unless you are ready to do some recalibration too. Since the cement is delivered at a fixed speed, the admixtures and water are both based on the rate of cement delivery. So if belt speed is changed, the water and admixtures need to be changed to maintain the same final concrete mixture design. Once calibration is complete per the guidelines, you should be ready to start mixing and pumping.

Loading Operations

There are two main ways to use a volumetric batch plant. One way is by filling the truck with all the materials at a facility and transporting the unit to the job site, where it is emptied and then run back to refill. The other way, which is the way we do it, is to set up the volumetric batch plant at a job site, park a portable cement silo and excavator next to it, and continuously batch throughout the job (refer to Fig. 2 and 3). Our batch plant is a stand-alone unit mounted on a trailer with a motor to supply hydraulic power. We only use this unit on larger jobs that will take at least 3 days or require over 130 yd^3 (100 m^3) of material because mobilization is a little costly. Regarding manpower, we have one crew member who oversees the volumetric batch plant and the shotcrete pump. However, the nozzleman still has ultimate control over the shotcrete pump via a remote control. The batch plant operator also has support from the excavator operator, who keeps the batch plant properly fed with cement, sand, stone, admixtures, and water. Using volumetric batch plants would work incredibly well for big projects that are far away from a ready-mix plant.

Advantages of On-site Volumetric Batching versus Ready-mix

There are many advantages of volumetric batching on site over plant-produced ready-mix. I understand a lot of shotcrete contractors in many parts of the country have no problem dealing with their local ready-mix companies. Unfortunately, that does not seem to be the case in our part of the country. I often find it difficult to deal with the ready-mix companies, especially on a job where you want to shoot 60 to 80 yd^3 (45 to 60 m^3) a day and are often requesting short loads with less-than-maximum truck capacity.

Some ready-mix trucks may take a little longer than others. On site, when shooting shotcrete, if there is a small issue that delays the shooting, one can find that several concrete trucks are very quickly waiting in line. With the volumetric batch plant, our crew leader doesn't even have to think about the mixture and can concentrate on his job, which is to shoot and finish a good project. The batch plant can produce material as fast or as slow as you want it, so you never have to worry about shooting speed and backing up trucks. Hot loads

Fig. 2: Batch setup

Fig. 3: Alternate view of equipment setup

are nonexistent with the batch plant because the only mix time is in the auger. If there is a pump issue that takes an hour to fix, the auger is just cleaned out and ready to go again. Without the batch plant, you need to send back the 7 yd^3 (5 m^3) in the ready-mix truck already on site waiting to discharge its load and worry about the next truck, which is likely already being batched.

We work mainly on large swimming pools with our volumetric setup. On these large pool projects, we are shooting floors and walls the same day. With the ability to adjust the mixture on site, we can make the shotcrete mixture for the floor a little bit wetter (while still not exceeding the maximum *w/c*) and then dry it up a bit when moving back to the wall, simply by adjusting a knob. This is not possible with a ready-mix truck.

In remote areas where ready-mix isn't available, volumetric batching can be easily used. Mixture adjustments can also be easily made. If a ready-mix truck shows up with an unpumpable mixture, the only options are to send the truck back and figure out what to do or add a pumping agent to the mixture, which can be detrimental to the final product. With the volumetric batch plant, some parameters can be adjusted if pumpability is suffering, without hurting the final outcome of the material. Having ultimate material control on-site can definitely save time and money on the right job.

I have found that volumetric batching is not very common in the wet-mix shotcrete industry, and I welcome any questions concerning the subject—whether you are looking to get into it, need it done for a specific project, or just want to learn more.

***Mason Guarino** started in the pool industry when he was 14, learning how to install reinforcing bar. Since then, he has worked in all phases of swimming pool construction. Guarino has been with South Shore Gunite Pools & Spas, Inc., full-time since graduating from the Wentworth Institute of Technology with his BS in construction management in 2009. Guarino is an ASA Board member and an ACI Certified Nozzleman.*

Material Velocity at the Nozzle

By Nicolas Ginouse and Dr. Marc Jolin

Since the early days of shotcrete, the reduction of rebound has been one of the major technical challenges of the industry due to its obvious impact on material and labor costs and, although less recognized, its detrimental effect on material properties. Although today, rebound mechanisms are still poorly understood from a physical and mathematical point of view, it has been shown that the impact velocity of particles plays an essential role on shotcrete rebound (Armelin et al. 1999). It is, therefore, essential to have a precise idea of the impact velocities generated by a given shotcreting configuration (for example, nozzle type, process, distance, and angle) in order to allow optimization of rebound. In practice, shotcrete material velocity is adjusted by changing the input airflow at the gunning machine in dry-mix shotcrete or at the nozzle in wet-mix shotcrete. These adjustments are currently based on the nozzleman and machine operator's experience.

This "Technical Tip" presents the experimental setup developed in the Shotcrete Laboratory at Laval University in Québec, Canada, to measure particle velocities at the nozzle outlet. Velocity values obtained for dry- and wet-mix shotcrete will also be discussed. In order to reproduce a realistic shotcrete spray, shotcreting equipment and mixtures common in the industry were used. An Aliva 246.5 with a 0.95 gal. (3.6 L) electric rotor and a 1.5 in. (37 mm) double-bubble nozzle (Fig. 1) were used for the dry-mix process. For the wet-mix shotcrete, an Allentown Powercreter 10 pump and a 2 in. (50 mm) hose with a short rubber "convergent" nozzle (Fig. 2) were used. In both cases, conventional dry and wet shotcrete mixtures supplied by King Packaged Materials were shot.

A pressure gauge and an electronic airflow meter were used to measure the input air pressure and the volume of airflow, respectively. The input air pressure was kept constant and equal to 100 psi (700 kPa) for all shotcreting tests. For the velocity measurements, a high-speed imaging system with a 1250 frames-per-second capacity was used to film the shotcrete spray. As illustrated in Fig. 3, this high-speed camera was placed perpendicular to the horizontal nozzle axis to visually capture the entire stream of particles. Note that for these measurements, the nozzle was kept motionless because the goal was to study the material as it exited the nozzle.

One of the most impressive portions of the setup was the software for the image analysis. The software tracked, frame by frame, the recorded particle's position as it exited the nozzle (refer to Fig. 4) to deduce nozzle velocity. A second analysis system included an in-house Matlab® program to correct optical errors induced by the camera lens and positioning.

The experimental measurements show that the particle velocities are not uniformly distributed around the (horizontal) spray axis. Indeed, in both configurations (dry and wet), the maximum

Fig. 1: Double-bubble dry-mix nozzle

Fig. 2: Rubber wet-mix nozzle (Bolduc 2009)

velocity is reached along the spray axis—that is, the centerline—and reduces gradually toward the edges of the spray. More precisely, centerline velocities obtained in dry- and wet-mix shotcrete are respectively about 1.75 and 1.32 times higher than the velocities measured at the spray edges. The maximum centerline velocity is about 78.3 mph (35 m/s) with the double-bubble nozzle (dry), decreasing gradually to 44.7 mph (20 m/s) at the spray edges. In the wet-mix case, velocity distribution is more uniform; the velocity difference is lower with a centerline velocity equal to 73.8 mph (33 m/s) and an edge velocity of 55.9 mph (25 m/s). The nozzle type and process can explain

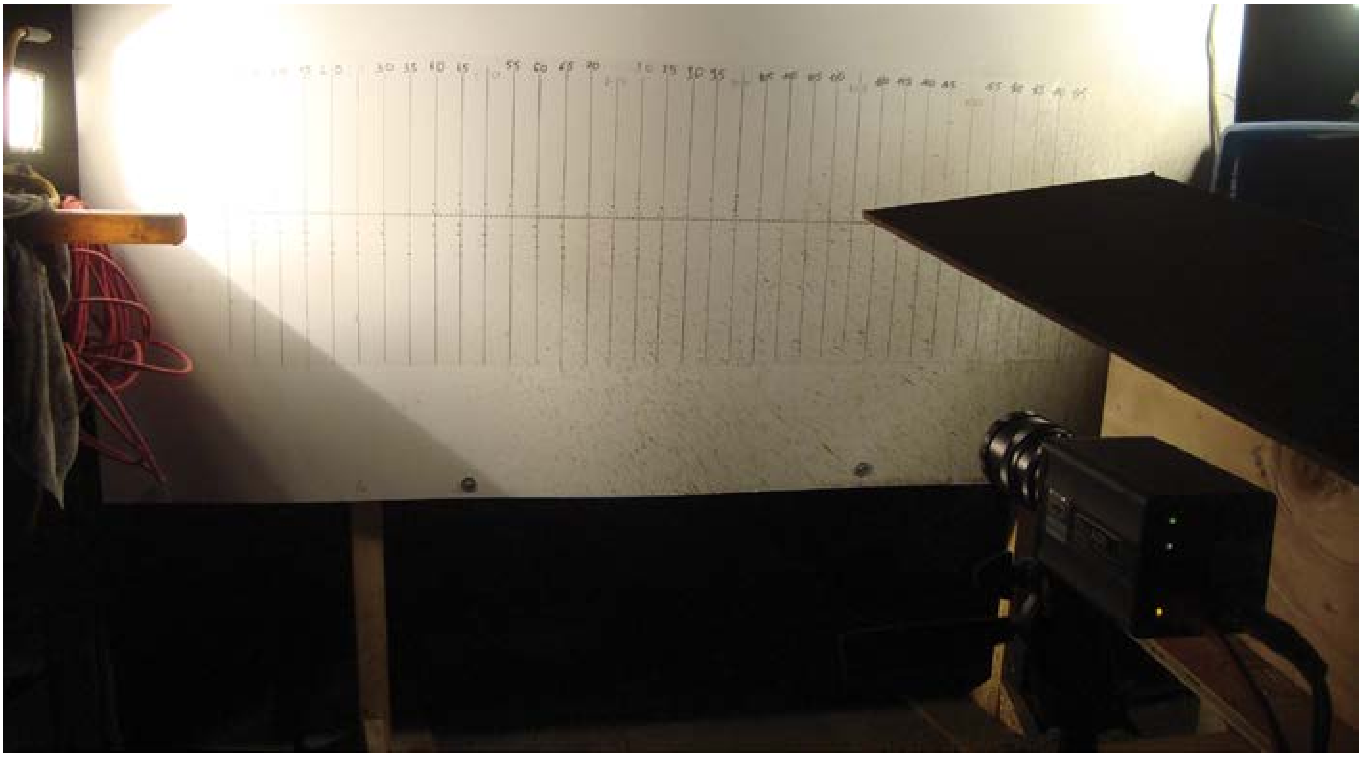

Fig. 3: High-speed camera ready to film a shotcrete spray

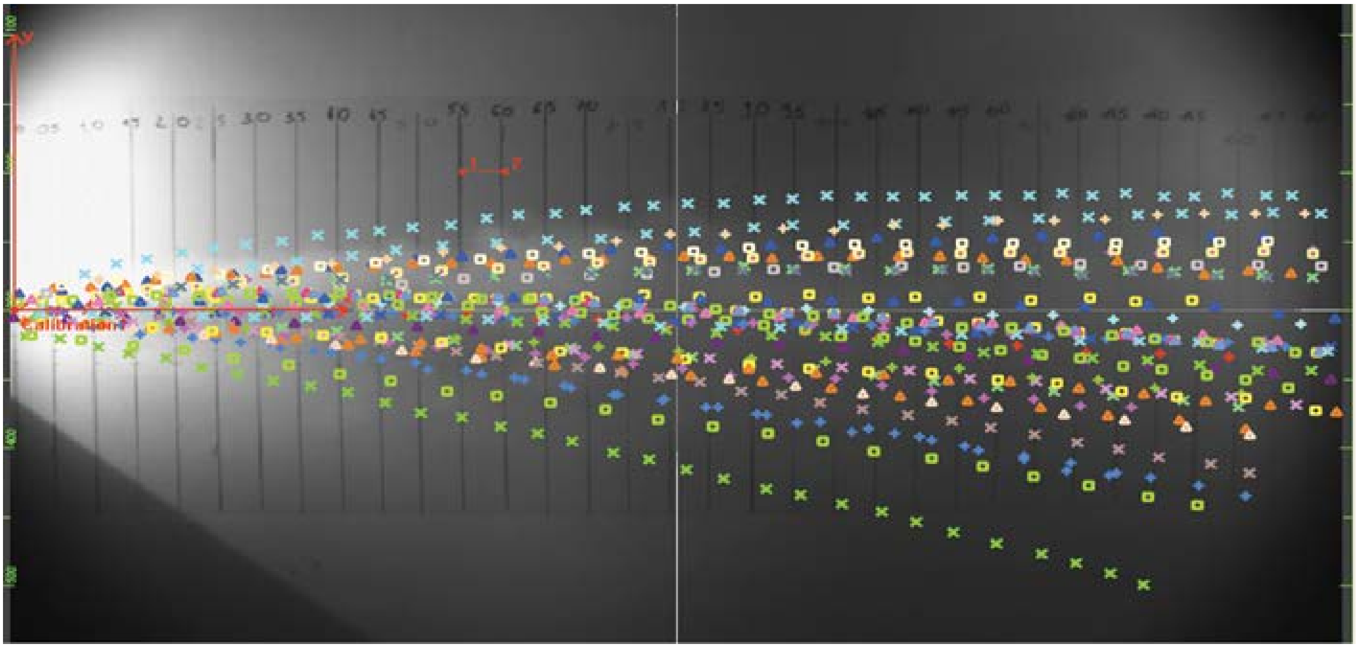

Fig. 4: Particle tracking performed using image analysis software (Jolin and Ginouse 2012)

this difference in velocity distribution. First, the double-bubble nozzle used in dry-mix shotcrete induces more turbulence, slowing down peripheral particles, compared with a "convergent" wet-mix nozzle where the air ring seems to produce the opposite effect. Second, the existence of a lubricating layer formed within the delivery hose during pumping can also facilitate peripheral particle acceleration by reducing friction with the internal nozzle walls (Kaplan et al. 2005). Indeed, according to yet-unpublished work conducted in Laval University's lab on wet-mix shotcrete, the periphery of the wet-mix spray contains more cement paste and fine aggregates compared to its core. Therefore, this lubricating layer appears to be conserved while passing through the nozzle, confirming its potential effect on peripheral particle acceleration.

The average velocities calculated from the centerline and edge velocities provide further information on the effect of equipment and process on outlet velocity. In both cases, average velocities are very similar (61.5 mph [27.5 m/s] for dry-mix and 64.9 mph [29 m/s] for wet-mix). In our experiments, we used the same input airflow of 200 ft^3/min (5.7 m^3/min) for both processes. Although it is commonly believed that wet-mix shotcrete requires less pneumatic energy to accelerate the particles than the dry-mix process, in which airflow is also used to convey dry material from the gunning machine to the nozzle, the same input airflow generated similar average velocities. To explain this somewhat unexpected similarity, we must also consider the amount of material (mass) that is accelerated or conveyed in each process. In fact, even if the dry-mix shotcrete configuration required more airflow to reach a given average outlet velocity, our wet-mix shotcrete case required acceleration of about three times more material (in term of mass). The output mass rate (pumping rate) was about 6.2 lb/s (2.8 kg/s) with the Powercreter 10 against 2.0 lb/s (0.9 kg/s) with the Aliva 246.5.

Based on the results presented, it is the nozzle type, the shotcrete process, and the output rate of material that will primarily affect the outlet velocity distribution. Moreover, in the wet-mix process, the lubricating layer induced by the pumping phase and the air ring positioning seem to provide favorable conditions to create a more uniform velocity distribution out of the nozzle. The next phase of this research will take advantage of the complete velocity profiles generated and concentrate on the material rebound phase of the application process. It is believed that, once equipped with experimentally validated velocity profiles, the description and optimization of rebound is just around the corner.

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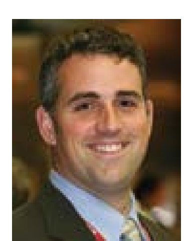

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Reaching 20 MPa (2900 psi) in 2 Hours is Possible

By Simon Reny and William Clements

In the mining and tunneling industries, time is critical; and as the mining/tunneling cycle becomes shorter, production increases. Shotcrete is often used for ground support when using the drill and blast method or other tunneling methods. But before reopening access for the next phase of the underground heading, the applied shotcrete must reach a minimum compressive strength to ensure the safety of the workers going into the heading. To speed up the mining and tunneling process, King Packaged Materials Company has been continually investigating different approaches to obtain the minimum required compressive strength as fast as possible. By using high-early-strength cement (Type III or Type HE) and a high accelerator dosage, it is possible to provide a shotcrete mixture design capable of reaching early-age compressive strengths of up to 7 MPa (1000 psi) in 4 hours. But to go over this previous limit, the cement technology needed to be reviewed. Working with calcium sulfo-aluminate cement (CSA), a Rapidset Cement technology from CTS Cement, King has developed a research program to bring early-age compressive strength gain to another level. One of the challenges in shotcreting with Rapidset Cement, as its name implies, is that it sets almost instantly. This can prove difficult when casting test specimens. Combining the use of the Rapidset Cement technology with the dry-mix shotcrete process provides a solution for reducing the mining and tunneling cycle.

Fig. 1: Shooting test panels above ground in winter conditions

Fig. 2: Shooting test panels and end beams on surface in summer conditions

The testing program included a first phase where the cement paste was optimized with the use of different pozzolans. Following this initial testing, the target final set time was established to be 10 minutes after shooting. The rapid-strength-gain dry-mix shotcrete went through several levels of testing prior to its availability for commercial use. Initially, the rapid-strength-gain dry-mix shotcrete was tested internally by King in both winter and summer conditions above ground (refer to Fig. 1 and 2). Following that, the rapid-strength-gain dry-mix shotcrete was tested in both a mine training facility (to observe the effect of underground conditions) and at Laval University (Quebec City, QC, Canada), where all parameters of the shotcrete application could be controlled. The final portion of the testing protocol involved testing the rapid-strength-gain dry-mix shotcrete underground at a mining facility in Northern Ontario under a cemented sand-fill section.

Results

Shooting operations were conducted using both the Aliva 246 and Aliva 252 dry-mix shotcrete machines. Regular shooting procedures were followed as described in ACI 506, "Guide to Shotcrete."[1] During the first two phases of testing, a standard mining shotcrete (produced by King) was used as a control mixture to make sure all of

Fig. 3: End beams in a steel mold after shooting underground

the different parameters were typical to normal shotcrete operations. The control mixture results met the usual standard; therefore, these results are not presented in the article as they are not relevant to the topic. Setting time was determined using a hand-held penetrometer in accordance with ASTM C1117, "Standard Test Method for Time of Setting of Shotcrete Mixtures by Penetration Resistance (Withdrawn 2003)." Early-age compressive strength was determined using the end-beam test method, adapted from ASTM C116, "Test Method for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (Withdrawn 1999)"[2] (refer to Fig. 3). Later, age compressive strength was determined in accordance with ASTM C1604, "Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete." The boiled absorption and volume of permeable voids was determined in accordance with ASTM C642, "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete." Also, the shotcrete nozzleman was asked to provide comments regarding the evaluation of the material (including rebound) based on his experience. The rapid-strength-gain dry-mix shotcrete was tested for all of the properties listed above at different material and ambient temperatures in order to observe the effects of temperature on the shotcrete mixture. Setting-time results are provided in Table 1. Early-age compressive strength and later-age compressive strength development curves with relation to material temperature are shown respectively in Graphs 1 and 2. The target compressive strengths in both graphs are typical for a mining shotcrete specification. The flexural strength results are presented in Table 2. The volume of permeable voids and boiled absorption results are given in Table 3.

Table 1: Set time results

Date	Jan-12	Jun-13	Dec-13	Feb-13
Final set time	4 minutes	4 minutes	6 minutes	n/a

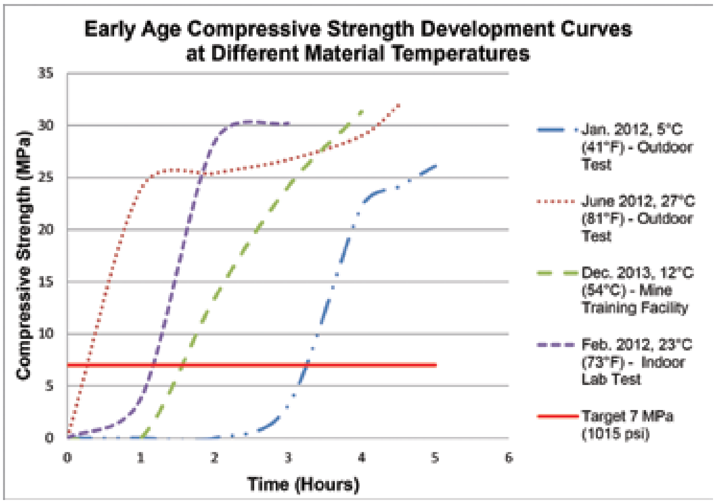
Table 2: Flexural strength results

Date	Jan-12
Initial material temperature	5°C (41°F)
7 days	5.6 MPa (810 psi)
28 days	6 MPa (870 psi)

Table 3: Volume of permeable voids and boiled absorption results

Date	Jan-12	Jun-12	Feb-13
Initial mix temperature	5°C (41°F)	27°C (81°F)	23°C (73°F)
Volume of permeable voids, %	15.8	15.0	15.9
Boiled absorption, %	7.1	7.0	7.1

Graph 1: Early-age compressive strength of end beam specimens



Graph 2: Later-age compressive strength of shotcrete cores

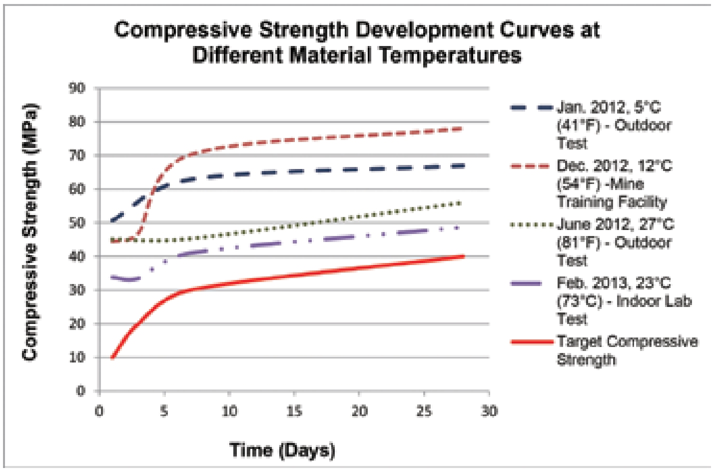


Fig. 4: King representative working with mining personnel to perform maintenance on a dry-mix shotcrete machine

Table 4: In-place test results from underground testing

Date	Mar-13	Jun-13
Temperature	20°C (68°F)	23°C (73°F)
Set time	10 minutes	N/A
Compressive strength at 1 hour	0.7 MPa (101 psi)	12.4 MPa (1798 psi)
Compressive strength at 1.5 hours	9.6 MPa (1392 psi)	N/A
Compressive strength at 2 hours	15.6 MPa (2263 psi)	14 MPa (2031 psi)
Compressive strength at 3 days	30.1 MPa (4366 psi)	41.3 MPa (5990 psi)
Compressive strength at 7 days	45.4 MPa (6584 psi)	42.4 MPa (6150 psi)
Compressive strength at 28 days	47.5 MPa (6889 psi)	51.2 MPa (7426 psi)
Volume of permeable voids, %	19.0	19.3
Boiled absorption, %	8.7	9.0

Various nozzlemen who shot the material in the lab or on the surface commented that the rebound levels were as low as or even lower than silica-fume-enhanced dry-mix shotcrete. They also added that the water was easier to adjust for the proper consistency and the rapid-strength-gain dry-mix shotcrete seemed to be less sensitive to water fluctuation than the control mixture.

The in-place underground testing brought minor daily challenges that a good product should be able to overcome. In this case, when the test was conducted in March 2013, the equipment was in poor condition and required maintenance prior to shooting (refer to Fig. 4). Even after emergency maintenance was performed on the equipment, the material feeding rate was not as consistent as usually expected.

Results from the in-place underground testing program with respect to set time, early-age compressive strength, later-age compressive strength, ambient temperature, volume of permeable voids, and boiled absorption are shown in Table 4.

Nozzlemen who shot the material underground provided the same comments as the nozzlemen who shot the material in lab/surface conditions, which were that the rebound levels were as low as or even lower than silica fume-enhanced dry-mix shotcrete.

Discussion

The early-age compressive strength curves presented in Graph 1 indicate that the material temperature had the largest effect on the time taken to reach compressive strengths in excess of 20 MPa (2900 psi). It should be noted that, even with an initial material temperature of 5°C (41°F), it was possible to reach compressive strengths in excess of 20 MPa (2900 psi) within 4 hours after shooting. The later-age compressive strength curves presented in Graph 2 indicate that the material temperature did not have a major impact on later-age compressive strengths, and all of the samples tested were shown to exceed the target compressive strengths of 10 MPa (1450 psi) at 24 hours, 20 MPa (2900 psi) at 3 days, 30 MPa (4350 psi) at 7 days, and 40 MPa (5800 psi) at 28 days. It should be noted that the lower compressive strength results for the "Indoor Lab Test" (tested Feb. 2013) in Graph 2, can be attributed to the fact that the material was shot at the wettest possible consistency without sloughing. The flexural strength results presented in Table 2 are very similar to results that would be expected from a normal portland cement-based, silica fume-enhanced dry-mix shotcrete. When comparing the early-age compressive strength results between values obtained in lab/surface conditions to underground conditions, it is apparent that the same level of strength development has not been shown to be present in underground conditions. It is possible that this could have been caused by a higher water-cement ratio (*w/c*) being used underground, as it can be more difficult to visually attain the proper consistency in underground conditions.

It is also possible that sand lenses could have been present in end-beam samples due to the poor condition of the shotcrete equipment used underground. Future testing will help provide values that can be expected for early-age compressive strength in underground conditions.

Temperature has a big impact on early-age compressive strength (same as with portland cement), but since the goal of the testing program was to show it is possible to reopen the heading when compressive strengths reach at least 7 MPa (1000 psi) (approximately 1 or 2 hours), the slight reduction in early-age compressive strength in underground conditions was not considered an issue. Therefore, ambient temperature and temperatures of the dry material and water must be controlled and monitored to ensure safety. The set-time results were found to meet the requirements of the testing program and were, therefore, satisfactory.

The absorption values are higher than usual, but the commonly used guidelines that are proposed in literature and generally accepted in the industry[3] were all obtained using portland cement-based shotcrete, so the values available in this test program must be taken as data to be collected for further development. These higher values could possibly be related to shooting with too high of a *w/c* or poor compaction/consolidation which could also explain the lower compressive strength results.

The acceptable or lower rebound level can be explained by the combination of the different pozzolans and the fineness of the calcium sulfo-aluminate cement (CSA). CSA cements are usually finer than normal portland cement, causing increased adhesion and compaction. All nozzleman pointed out the fact that the water was easier to adjust and seemed to fluctuate less than conventional portland cement-based dry-mix shotcrete.

Conclusions

1. It is possible to obtain 20 MPa (2900 psi) or even higher compressive strengths at 2 hours in the right conditions using dry-mix shotcrete with CSA for mining applications.
2. The rapid-strength-gain dry-mix shotcrete should be considered a very robust product that is suitable for regular mining and tunneling operations.
3. Early-age strength development seems to be sensitive to ambient temperatures.
4. Absorption results are higher than usual portland cement-based, silica fume-enhanced shotcrete mixtures.

Fig. 5: Rapid-strength-gain dry-mix shotcrete modified with red pigment

5. In-place testing provided sufficient confidence to the mine to include this new product in the mining cycle. Since being introduced into the mining process, the mine requested that a pigment be added for safety reasons to differentiate where this mixture is used instead of their regular dry-mix shotcrete (refer to Fig. 5).

Looking forward, the next steps are:

- To improve the formulation for higher strengths at earlier ages, since the technology provides sufficient evidence to believe it is possible;
- To develop a formulation with different steel fiber dosages and run the appropriate testing; and
- The boiled absorption level must be monitored and investigated, to evaluate if the lower results are the nature of the new technology or result from poor compaction.

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Sustainable Shotcrete Using Blast-Furnace Slag

By Philip Sawoszczuk, Dr. Michelle Nokken, and Dr. Marc Jolin

Two shotcrete mixtures were designed based on sustainability for use in mining ground support. The sustainable shotcrete mixture contained both fine and coarse pelletized blast-furnace slag aggregates. The control mixture contained regular concrete sand as the fine aggregate and pelletized blast-furnace slag as the coarse aggregate. The cementing materials were the same for both mixtures and consisted of 85% portland cement, 7.3% granulated blast-furnace slag, and 7.7% silica fume. The sustainable shotcrete mixture—composed of a total of 77.71% recycled materials, including slag cement, slag aggregates, and silica fume—achieved an average compressive strength of 4569 psi (31.5 MPa) at 28 days, in addition to a hardened density that was 7.6% lighter than the control mixture. The results indicate the potential and feasibility of the sustainable shotcrete mixture for mining companies as they strive to meet more stringent environmental regulations and expectations.

Introduction

Concrete and shotcrete are consumed at a rate of 11 billion tons (9.98 billion metric tons) per year, making it the most consumed material on Earth.[1] Incorporating waste materials such as blast-furnace slag or silica fume into concrete and shotcrete can go a long way toward reducing concrete's impact on the environment by recycling them into a useful product and replacing new minerals. Disposing of this waste has always been a concern for industry; until very recently, it has been dealt with by the most economic means possible. Unfortunately, the most economical waste disposal methods were often damaging to the environment. Today, laws, regulations, treaties, and public pressure are increasingly forcing all industries to find more environmentally and socially responsible ways to manage waste. As our scientific and technological understanding increases, waste is being refashioned into products looking for a purpose. In this light, with some technical knowledge, waste can be processed and used economically, with little or no environmental impact. Adding to this trend is the growing awareness of the high level of sustainability of the shotcrete process.[2] This article will explore and discuss the performance of two shotcrete mixtures, designed to maximize sustainability while meeting the performance criteria required for underground ground support.

Problem Definition and Research Significance

Industrial wastes can have detrimental impacts to human health, the environment, and to society. Is it possible to use part of these wastes in ground support shotcrete in a sustainable fashion? Pelletized and granulated blast-furnace slag aggregates have not been studied in shotcrete previously and offer a promising channel to increase the recycled material content of shotcrete, as well as making it less dense, offering further benefits to the yield of fresh shotcrete per weight of dry material. The research project will help qualify the feasibility of using these aggregates in shotcrete mixtures for ground support.

Objectives

The goal of this project was to investigate a dry-process shotcrete mixture design that:

1. Recycles various waste products;
2. Meets standard safety criteria for shotcrete materials;
3. Meets performance criteria for underground ground support shotcrete;
4. Meets durability criteria for underground ground support shotcrete; and
5. Meets economic and process feasibility criteria.

Mixture Design Ingredient Selection

Blast-furnace slag from the iron refining industry has been widely used and accepted in the concrete industry, is commercially available, and already has been the subject of shotcrete research as a cementitious ingredient in shotcrete under the form of ground-granulated blast-furnace slag (GGBFS).[3*] It is produced alongside pig iron when iron ore, limestone, and coal are heated in an enormous blast furnace at temperatures reaching around 3450°F (1900°C). As the molten iron sinks to the bottom of the furnace, impurities containing silicates and sulfates are captured by the calcium carbonate of the limestone and float to the top. The pig iron is separated out at the bottom of the furnace, while the slag is skimmed off the top of the molten pig iron.[4-6] After accounting for marketable pig iron recovery, about 10 to 15% by mass of pig iron output is slag.[7] Blast-furnace slag has steadily gained popularity for various uses, making it an economically viable option. GGBFS has been studied, used, and proven to be a useful addition to concrete mixtures as a supplementary cementitious material.[8] Blast-furnace slag has been studied as both a coarse aggregate, as expanded blast-furnace slag,[9] and as a fine aggregate[10,11] under the form of non-ground-granulated blast-furnace slag (n-GGBFS) in concrete mixtures, but not in shotcrete mixtures. This project investigated the feasibility of using blast-furnace slag, in multiple forms, to produce dry-mix shotcrete mixtures with the explicit goals of sustainability and meeting basic performance criteria for underground shotcrete. Blast-furnace slag aggregates and supplementary cementitious material (SCM) are also as safe to use in shotcrete applications as conventional aggregates and cement, thus meeting the safety objective.[12]

*Note: ACI and ASTM International now use the term "slag" in place of "ground-granulated blast-furnace slag," but to eliminate confusion in this article, we will use the older term GGBFS because we are also discussing pelletized slag as well as the cementitious GGBFS.

Mixture Designs

Dry-mix shotcrete was selected for this project, as it offers users more control over placement parameters. It is better suited for lightweight aggregate mixtures and is a current placement method in many mines.[13] The two mixture designs used in the experimental phase of this project are shown in Table 1, with pictures of the ground blast-furnace slag aggregates in Fig. 1 and their combined gradations in Graph 1.

Fig. 1: Pelletized coarse (1.15 to 9.50 mm [0.05 to 0.37 in.]) (right) and pelletized fine (0 to 2.36 mm [0 to 0.09 in.]) (left) blast-furnace slag aggregates

Graph 1: Comparison of Shotcrete Mixture Design Gradations and ACI 506R Limits

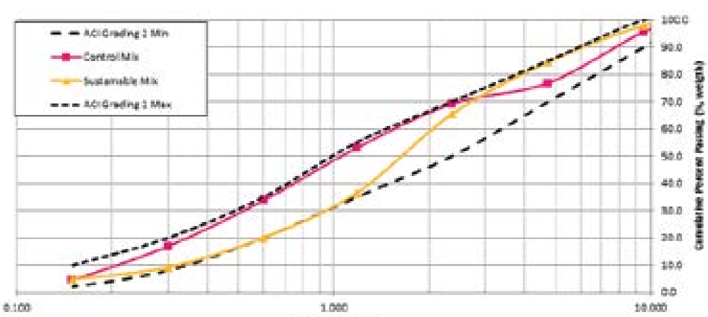

Table 1: Mixture designs for dry-mix shotcretes

Ingredients	Control mixture: Dry ingredient, (%, weight)	Control mixture: Quantity, lb/yd³ (kg/m³)	Sustainable mixture: Dry ingredient, (%, weight)	Sustainable mixture: Quantity, lb/yd³ (kg/m³)
Type GU cement	20.40	656 (389)	22.10	649 (385)
GGBFS cement (90% BFS, 10% GU)	1.75	56 (33)	1.90	56 (33)
Silica fume	1.85	59 (35)	2.00	59 (35)
Concrete sand (0.08 to 5.00 mm)	57.00	1831 (1086)	0.00	0 (0)
n-GGBFS fine (0.15 to 2.36 mm)	0.00	0 (0)	59.30	1743 (1034)
BFS coarse (1.18 to 9.50 mm)	19.00	610 (362)	14.70	432 (256)
TOTAL DRY	100.00	3211 (1905)	100.00	2936 (1743)
Water (e/c = 0.45 theoretical)		347 (206)		344 (204)
TOTAL WET		3558 (2111)		3282 (1947)

Experimental Procedure

The raw materials were dried, weighed, blended dry, and packaged in the laboratory using ovens and the sun for drying, bench-top scales for weighing, a concrete mixer for blending dry ingredients together, and plastic bags for packaging. Roughly 530 lb (240 kg) of each dry mixture was prepared at the King Packaged Materials Facility in Blainville, QC, and shipped to Laval University in Québec City, QC, for testing. The world-class shotcrete testing facility at Laval University features mass balance monitoring for all inputs, including material weight, water, and air, in addition to an accurate rebound measurement system and a fully equipped concrete testing lab. A certified nozzleman placed the samples. An Aliva 246 dry-mix shotcrete machine was used for testing, using 66 ft (20 m) of a 1-1/2 in. (38 mm) inside diameter, 2 in. (50 mm) outside diameter hose, with a double-bubble type nozzle and a water ring immediately at the end of the hose, right before the nozzle. A hydromix assembly was not available during the test period, but would have offered longer and better mixing. The machine, the operator, and the material were all located on a large scale to weigh the outgoing shotcrete material. The material was shot against a steel panel with a beveled edge that hangs from a load cell to measure rebound. The material was also shot into two standard ASTM C1604/C1604M[14] wood panels measuring 24 x 24 x 3.5 in. (610 x 610 x 90 mm) to extract cores for compressive strength, boiled absorption, volume of permeable voids, chloride ion permeability, and density testing.

Fig. 2: Aliva 246, material and operator on scale (top left), double bubble nozzle (top middle), short hydromix nozzle assembly (top right), shotcrete panels (middle left), rebound panel (middle middle) and shooting area overview (middle right), fresh control mixture on rebound panel (bottom left), measuring buildup (bottom middle), shooting control mixture panel (bottom right)

Experimental Results

Table 2 presents the results achieved during the testing phase.

Discussion

The water-cementitious material ratio (*w/cm*) of the fresh shotcrete for the control mixture was 0.33 compared to 0.52 for the sustainable mixture. Both of these were determined by taking the initial mass and then drying freshly shot shotcrete in a microwave until a constant mass is achieved. The ratio is then calculated using the mixture's in-place cementitious content, measured by washout over an 80 μm sieve immediately after shooting. The in-place cementitious content was higher for the control mixture, as a result of the higher rebound. This method does not distinguish between the water consumed to hydrate cement and the water absorbed by the aggregates. Blast-furnace slag aggregates absorb between 6 to 9% water by mass, as compared to 0.6% for natural sand.[12] It follows that a significant part of this water content can be attributed to absorption by the slag aggregates and that the actual *w/cm* is less than 0.52 for the sustainable mixture.

The air flow for the control mixture, at 196 ft^3/min (5.55 m^3/min), was higher and closer to the normal air flow rate for standard shotcrete mixtures with the selected equipment than the sustainable mixture, which was 136 ft^3/min (3.85 m^3/min) or 30.7% less. The reduced air flow rate for the sustainable mixture was a result of unfamiliarity of the shooting performance of the mixture. The all-slag mixture was found to be stable at a higher *w/cm*, masking the requirement for a higher air-flow rate to produce a denser and stronger hardened shotcrete. Because the slag particles are smooth and more slippery within the cement matrix than natural sand, they should decrease the water demand to achieve a proper fresh shotcrete consistency. Yet, because the particles are porous, they tend to absorb more water than natural concrete sand, offsetting the more fluid consistency. The mixing time was also shortened, due to the unavailability of a long hydromix nozzle assembly, resulting in a less than ideal mixing time for either mixture.

Table 2: Test results

Criteria	Method	Control mixture	Sustainable mixture	ACI 506.5R minimum[16]	ACI 506.5R maximum[16]
Water content to cementitious ratio	U. Laval	**0.33**	**0.52**	0.35	0.45
In-place cementitious (%, mass)	U. Laval	37.1	31.8	—	—
Average air flow, ft^3/min (m^3/min)	U. Laval	195.9 (5.55)	135.8 (3.85)	—	—
PERFORMANCE CRITERIA					
Compressive strength at :					
3 days, psi (MPa)	ASTM C1604[14]	2495 (17.2)	**1697 (11.7)**	2176 (15)	—
7 days, psi (MPa)	ASTM C1604[14]	**4235 (29.2)**	**2698 (18.6)**	4351 (30)	—
28 days, psi (MPa)	ASTM C1604[14]	**5656 (39.0)**	**4569 (31.5)**	5802 (40)	—
Hardened density, lb/yd^3 (kg/m^3)	U. Laval	3600 (2136)	3327 (1974)	—	—
Rebound (%, mass)	U. Laval	**34.7**	14.8	10[*]	30[*]
DURABILITY CRITERIA					
Boiled absorption (%)	ASTM C642[15]	**10.26**	**15.45**	—	8[†]
Volume permeable voids (%)	ASTM C642[15]	**20.20**	**26.69**	—	17[†]
Chloride permeability (coulombs)	ASTM C1202[17]	1032	1843	—	—

[*]Rebound limits defined in ACI 506R, Table 8.1.[13]
[†]These limits are for normalweight aggregates and may not apply to lightweight aggregates, such as slag aggregates.
Note: **Bold** results do not conform to ACI 506.5R, "Guide for Specifying Underground Shotcrete," criteria.[16]

The sustainable mixture had 32%, 36%, and 19% lower compressive strength at 3, 7, and 28 days, respectively, compared to the control mixture. The blast-furnace slag aggregates are more porous, with a specific gravity of 2.3 for the fine aggregates and 1.7 for the coarse aggregates. The natural concrete sand has a specific gravity of 2.7, showing the slag aggregates are less dense.[12] Furthermore, the sustainable shotcrete probably suffered from less compaction and more voids than the control mixture due to lower air-flow rate used to project it, also increasing its overall porosity. According to strength theory, as voids and porosity increase in a material, strength decreases.[1] The sustainable mixture had a 7.6% lower hardened density than the control mixture. The experimental densities were close to those determined mathematically, with 3560 lb/yd^3 (2110 kg/m^3) versus 3600 lb/yd^3 (2140 kg/m^3) for the control mixture and 3280 lb/yd^3 (1950 kg/m^3) versus 3330 lb/yd^3 (1970 kg/m^3) for the sustainable mixture, perhaps indicating that the actual *w/cm* ratio was different than that measured experimentally, due to absorption and adsorption of water on the dried aggregates. Furthermore, the values of boiled absorption, volume of permeable voids, and chloride ion permeability are all higher in the sustainable mixture, indicating it is less dense or more porous.

Even the control mixture values for these criteria are above those proposed by ACI 506.5R, illustrating that the porous coarse slag aggregates alone greatly influence the total porosity and permeability of the final hardened shotcrete. The 42.7% reduction in rebound measured for the sustainable mixture can be partly attributed to the lower air-flow rate used to project it on the steel receiving plate. Future experiments at optimized air-flow rates will provide a better comparison. Both the sustainable and the control mixtures did not meet the ACI 506.5R criteria for compressive strength, boiled absorption, and volume of permeable void limits.[16] According to ASTM C1202, both mixtures are still classified as having low chloride ion permeability.[17]

All these factors illustrate the challenges and future opportunities of studying shotcrete mixtures based on lightweight slag aggregates. The water content and the air flow could be optimized in future experiments to increase success and achieve higher compressive strengths, while reducing permeability and porosity, especially when using lightweight blast-furnace slag aggregates.

Conclusions

Although the experimental phase did not meet performance and durability criteria for a suitable underground ground control shotcrete application as defined by ACI 506.5R, "Guide to Specifying Underground Shotcrete," it did meet the objective of sustainability, achieving an economically and technically feasible mixture composed of 77.7% recycled materials—including slag cement, slag aggregates, and silica fume—with an average compressive strength of 4570 psi (31.5 MPa) at 28 days and an average density 7.6% lighter than the control mixture. The comparatively low rebound of 14.8% on a vertical steel plate can be an additional benefit, increasing the yield of fresh shotcrete per unit of dry shotcrete material, along with the lower density, for the sustainable shotcrete mixture. In general, this article has illustrated the promising and positive aspects of increasing the use of industrial waste materials, such as blast-furnace slag aggregates in dry-mix shotcrete.

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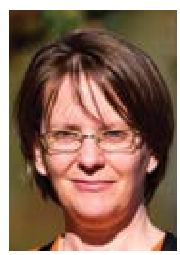

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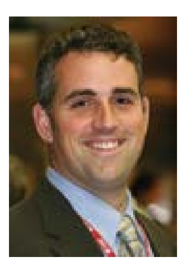

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Dry-Mix Equipment Maintenance

By Todd Ferguson

Maintaining your dry-mix shotcrete (gunite) equipment ensures that your crew will get the most efficient production, maximum service life, and safest operation from your machinery and accessories. The typical dry-mix shotcrete equipment setup includes a gunite machine, material nozzle, material hose, water hose, air compressor, and air hose. Equipment manuals from manufacturers should detail all the necessary steps for complete equipment maintenance. Still, it is important to review these procedures with members of the crew, especially those in charge of the equipment on a daily basis.

Dry-Mix Shotcrete (Gunite) Machines: Bowl Type

Gunite machine maintenance begins on the first day you put it into service. When setting up equipment for initial use, you will complete preventative maintenance procedures, such as lubrication. Two main classes of gunite machines are in use today: bowl-type gunite machines and barrel-style gunite machines. Both are considered "rotary" gunite machines (rotary guns), as they both are designed with rotating feed systems. These designs are in contrast to pressurized single- and double-chamber guns, which have fallen out of popular use. This article will focus on bowl-type designs (Fig. 1).

Bowl-type gunite machines contain a feed system including a material feed bowl, steel wear plate, rubber wear pad, and material outlet, also known as the "gooseneck." Owners will have to replace the wear plate, wear pad, and a polyurethane liner within the gooseneck at various intervals of service. Clean the entire bowl and oil its pockets each day to prevent accumulation. Feed bowls are either designed with steel or a combination of steel/polyurethane. To remove buildup on a steel feed bowl, use a hammer and chisel. To remove buildup on a steel/poly bowl, turn it upside down and strike it with a rubber mallet first to loosen any buildup material. Then turn the bowl right-side-up again and carefully remove the loosened material with a screwdriver.

Over time, the wear plate will become misshapen from constant contact with dry shotcrete material. Grooves may appear in the walls of the pockets or the surface of the plate may become uneven (that is, not completely flat). When this occurs, the wear plate will not function correctly, causing air leaks between the bowl and the plate or uneven rotation. The wear plate should then be resurfaced by "Blanchard" grinding or comparable technology described in the equipment manual (Fig. 2).

The wear pad functions as a seal between the wear plate and the gooseneck outlet assembly and is in direct contact with the flow of material. Over time, the wear pad will develop grooves from material passing over it and should be replaced. Grooves in the wear pad can allow excess material to cause additional wear on the plate. Manufacturers highly recommend replacing the wear pad as soon as grooves appear. Replacement at regular intervals will prolong the life of the wear plate, ensure the efficient flow of air in the system, and reduce escaping dust at the gooseneck assembly (Fig. 3). An overabundance of dust-creating materials on the job can lead to unsafe working conditions. Contractors should be sure to limit the exposure of their crew to potentially harmful components that may be present in dry-mix materials. If you find a mound of dry-mix material next to your gunite machine, there is something wrong and the equipment should be checked. The wear pad is the first item to check for wear when material is escaping. Never try to extend the life of a wear pad with excessive tightening of the hold-down clamps. This can cause undue stress on other components on the machine and could potentially lead to unsafe operation (Fig. 4).

A strip of felt provides a seal where the bottom of the hopper meets the wear plate. This felt seal should be lubricated daily until it is flexible enough to provide an adequate seal. Once the felt seal is dry and hardened, you will need to replace it. Some manufacturers have provided a conve-

Fig. 1: Bowl-type rotary gunite machine (dry-mix shotcrete machine)

Fig. 2: Worn plate (left), new plate (right)

Fig. 3: Gunite machine view of wear pad

Fig. 4: New wear pad (left), worn wear pad (right)

nient means of oiling and adjusting the felt seal from outside the hopper without dismantling the machine. This lubrication and adjustment is achieved through strategic access holes designed into the hopper. A felt seal that is in good working condition is critical to avoid letting dust escape between the hopper and the wear plate. As stated previously, excessive dust on the job can create a health risk to workers and must be controlled.

The gooseneck contains a polyurethane liner to prevent wear directly on the steel surface of the gooseneck. Replace the liner when it has worn through to prolong life of the gooseneck. The amount of wear is dependent on the type of materials being used; however, liners should provide approximately 80 yd^3 (61 m^3) of service. It is not advisable to operate the gun without this gooseneck liner for economic reasons. The liner comes with a smaller price tag than the gooseneck, so it only makes sense to keep the usable liner in place to accommodate the wear.

Various parts of the gunite machine require regular lubrication. Before every job, lubricate the bowl and plate with oil as specified in the equipment manual. When oiling the feed bowl, make sure to thoroughly coat the pockets of the bowl, which primes the steel for use and helps reduce the amount of dried material that sticks to the surface. The bowl and plate touch each other directly in the machine, so proper, regular lubrication helps reduce wear between these two components (Fig. 5).

Many gunite machines are entirely powered by air, which is used independently to rotate the feed system and to propel dry material out of the gooseneck through the material hose to the nozzle. These machines include an air motor that controls rotation of a series of gears and the main shaft. Air lines (that is, plumbing pipes and fittings) that deliver air to the motor are equipped with a filter and lubricator. The filter ensures that air going into the system is clean and the lubricator gives the passing air a small amount of oil. Both ensure smooth operation of the air motor. Inspect the air filter weekly and clean if needed. New machines may arrive from the factory with an empty air lubricator that is also closed to oil flow. It is critical when receiving delivery of a new machine to fill this lubricator and adjust the flow of oil. Before each job, make sure that the air lubricator is filled with oil according to the directions in the equipment manual. Manuals should include recommendations on the number of drops per second or minute, such as one drop every 10 to 15 seconds. On many gunite machines, the air motor is connected to a gear box, which requires lubrication. You should be able to check the oil level in the gear box by accessing a dipstick. Check this oil level regularly, for example, after every 40 hours of operation.

Gunite machines include material screens placed over the hopper to help prevent the introduction of aggregates larger than the machine is designed to process. Typical bowl-type gunite machines can process aggregates up to 3/4 in. (20 mm). It is common for material to build up on the material screen over time, which can reduce the size of the spaces in the screen. This may not be cause to worry because you want to prevent oversized rocks from entering the hopper. Keep material screens in good repair so they function as designed, and keep them in place over the hopper to help avoid accidents with the rotating agitator inside the hopper.

Within the feed system, a piece of metal called a rock shear is present to catch any large rocks that may have accidentally gotten into the machine. If a large rock comes into contact with the rock shear, the feed system will not rotate and you will need to shut down the machine to remove the rock. The rock shear is in direct contact with material flow so it is a wear item. Check the rock shear on a weekly basis. It can be rotated four times to place a clean edge in contact with material. You will also need to adjust the rock shear to the correct distance from the wear plate during setup.

Fig. 5: Gunite machine components

Fig. 6: New water ring (left), worn water ring (right)

General maintenance on a daily basis will prolong the life of your gunite machine. Be sure to disconnect the air line from the air compressor and bleed off any remaining air in the system when performing any maintenance on the machine. Do not reach down into the hopper when the air line is connected because the agitator could begin rotating, causing a dangerous situation. If air is flowing to the gunite machine and a valve is opened, that incoming air could cause rotation of the feed system, including the agitator—this is no place for your hands or arms.

Certain areas of the gunite machine will require daily cleaning. Some models may include an exhaust chamber to catch dust and prevent it from rising out of the hopper. This item is not necessarily considered a wear item, but it is important to keep it emptied out each day. Clean any built-up material from the inside of the hopper base, which could catch on the feed bowl and prevent rotation. Clean the main shaft and baseplate daily to ensure a smooth rotation of the feed system. An exhaust hose may be connected to the machine to further reduce dust in the working environment, which helps to provide workers with the cleanest, most breathable air.

Dry-Mix Shotcrete (Gunite) Nozzles

Dry-mix nozzles are designed to receive dry or pre-dampened material from the gunite machine and water from a source with adequate pressure. The two components mix together at the last moment before they are propelled onto the construction surface. Nozzle maintenance is important for achieving proper mixing of water and material within the nozzle. The water ring is the most important part of the nozzle to keep clean. The water ring, which may be brass or aluminum, includes holes to allow water to pass through at high pressure into the nozzle body during operation (Fig. 6). Be sure to inspect the water ring before a job to make sure these holes are free and clear from any buildup. Manu-

Fig. 7: Dry-mix nozzle components (showing "double bubble" style tip)

facturers also recommend coating the water ring with oil to prolong its usefulness. Replace the water ring when it cannot be cleaned or when it has become misshapen. Do not drill out the holes in the water ring because they are specifically sized to provide proper distribution of water into the dry-mix material flowing through the water ring.

Dismantle the nozzle assembly after each day of use and thoroughly clean the inside and outside to ensure performance on the next job. (Fig. 7) You may also be able to clean the nozzle without disassembly by one of two methods: 1) you can use the valves on the gunite machine to send air to the nozzle from the gunite machine without sending material. Combine this with water flow to the nozzle and you may be able to thoroughly clean the nozzle parts, including the water ring; or 2) you may achieve success without the use of compressed air by simply pointing the nozzle down and allowing water to flow through the nozzle's water connection.

Nozzles may either have a steel tip with a rubber liner or a polyurethane tip. If using a nozzle with a liner, be sure to inspect it regularly and replace the nozzle liner when worn through. The amount of wear is dependent on the type of materials being used; however, liners should provide approximately 80 yd^3 (61 m^3) of service. The nozzle liner should include "steps" or ridges that are built in to help mix material in the nozzle. (Fig. 8) These steps can be seen close-up or can be felt by touching inside the end of the nozzle liner. When steps have worn away from material flow, it is time to replace the nozzle liner. Nozzle tips should not be cut or shortened, as this can prevent material from mixing adequately in the nozzle. Without proper mixing within the nozzle, the quality of the concrete being placed on the construction surface is compromised. It may lead to uneven distribution of sand and cement, which can result in an unreliable or even unsafe structure. Polyurethane tip designs may last longer than a liner. Their overall longevity may vary depending on the thickness of the material used or overall design and shape.

Fig. 8: Dry-mix nozzle liner with interior steps/ribs

Fig. 9: Nozzleman using anti-static dry-mix hose

Material Hoses

Be sure to only use a material hose designed for dry-mix to ensure performance and allow for predictability in terms of wear. Before every use, inspect all material hoses, air hoses, and water hoses for cracking, abrasions, or excessive wear, and replace hoses if necessary. Hose fatigue will vary with the type of material being used. Squeeze and bend hoses to determine if they have become too thin or can be bent too easily. If you notice a split in the hose or if it appears "bleached out" and lightened in color, that hose may be due for replacement. Worn-out hoses can burst during operation, so it is important to monitor hose wear and replace as necessary (Fig. 9). Also inspect hose couplings regularly to ensure they are in safe working condition. A compromised coupling may become disconnected under pressure, causing risk to those within range. Look for any cracks, dents, or misshapen couplings and replace them right away. If couplings will be in direct contact with material during your job, be sure to cover the couplings to prevent buildup of material. For example, you may wrap the couplings with plastic. Hose fittings should be secured adequately to the hose and threads should be in good condition for use. To ensure the highest-strength coupled hose assembly, manufacturers and contractors should use elevator bolts instead of screws to install dry-mix couplings on hoses. Clean and grease all couplings daily to prolong their use. When using pre-dampened materials, hoses may be more susceptible to build up within the hose. This buildup could potentially cause a blockage. Be sure to review the following procedure on hose blockages with all members of your crew(s).

When dry-mix hose blockages occur, the nozzleman should:

- Hold the nozzle firmly and brace against a wall or scaffold (do not lay the nozzle down);
- Direct the nozzle in a safe direction;
- Signal to shut off the gun/pump and water/air input; and
- Bleed off pressure at the gun.

When clearing a plug out of a dry-mix hose:

- Shut down and relieve pressure as noted;
- Locate the plug by walking along the hose to find where the hard points are;
- Once the plug is located, disconnect the nearest location between the nozzle and the plug;
- Work on the hard points with a hammer to try to loosen them up. I would suggest using a carpenter's hammer rather than a sledgehammer, as you are only trying to loosen dry material by vibrating it—you do not want to damage the structure of the hose;
- Loosen up material from the nozzle end toward the gun. If you work the opposite way, you may just be allowing more material to get behind the plug and add to it;
- As you loosen up material, work to shake the loose material out of the end of the hose;
- Once the plug appears to be gone, have the nozzleman hold the hose while bracing himself, as stated previously. If the plug was loosened up properly, the material should just empty out of the hose as it normally would. The nozzleman should brace himself in case the plug was only partially cleared and lets loose; and
- If the plug persists, work to manually shake more material out of the hose on both sides of the plug and try to clear again when it seems to be loosened.

Use "whip checks" on all air hose connections at the air compressor and gunite machine. Consider using whip checks on material hose connections because they are also subjected to high-pressure air flow.

Additional Equipment

Equipment owners should follow all manufacturers' recommendations to prolong the use of their machinery and accessories. Consult all manuals for maintenance of any other equipment used on the job, such as an air compressor, dry-mix batch plant, or pre-dampener, and keep up with regular maintenance. Proper maintenance also ensures that dry-mix equipment will deliver maximum output and efficiency. Consider developing a user-friendly checklist to help organize and manage the daily and weekly maintenance of your dry-mix equipment.

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Where Are We Now with Sprayed Concrete Lining in Tunnels?

By Andrew Pickett and Dr. Alun Thomas

Traditional methods of sprayed concrete lining (SCL) tunnels (in soft ground) comprise a temporary primary lining of sprayed concrete with a sheet membrane inside and a permanent cast in-situ concrete lining, usually reinforced with steel bars. Even now, although it is widely accepted that sprayed concrete can be used as a permanent material, the traditional methods are applied to the majority of tunnels. This is wasteful in terms of money, time, and materials. Mott MacDonald is now providing design solutions for the use of permanent sprayed concrete with a variety of waterproofing solutions through its involvement as designers on major projects in the UK—in particular, soft ground tunneling, where the profile of the ground can be cut quite smoothly.

The design solutions have ranged from permanent sprayed concrete, sprayed onto a sheet membrane in a drained tunnel; permanent waterproof sprayed concrete in generally impermeable ground; and permanent sprayed concrete, sprayed in two passes with a spray-applied waterproofing membrane in between for cases where there is a higher risk of water ingress.

The focus of study has been on the last case in recent projects and, having examined the composite action, it has been found that significant load sharing can be obtained even with modest bonding at the membrane interface.

The issues related to the design of composite linings and the range of suitability for different functional requirements will be discussed in this paper, along with examples from recent projects of shallow tunnels in soft ground or weak rock.

Initial findings will also be reported from preliminary testing with BASF exploring single-shell tunnel lining solutions and bond strength between a sprayed membrane with permanent lining to demonstrate a greater composite action. This, coupled with some discussion on the most recent numerical modeling from a live project, will outline where SCL composite lining solutions are heading, expanding on the challenges that will have to be met to handle different situations as well as satisfying functional requirements to clients and the wider tunnel industry.

Design Options

There are now several options for SCL tunnels open to tunnel engineers to suit different geological and hydrological conditions and/or the client's functional requirements (refer to Fig. 1[1]). The SCL options can be broadly categorized into three types. Double shell linings (DSL) involve a sacrificial primary lining, which takes the temporary loads, and a secondary lining to take the permanent loads (refer to Fig. 2). This has significant pedigree, however, because the primary is considered temporary while the secondary is designed to take both long-term ground loads and hydrostatic, thereby providing a robust design. It is a lot thicker than CSL types.[2]

Composite shell linings (CSL) involve the primary lining taking the temporary loads and a proportion of the permanent load through composite action with the secondary lining. Single shell linings (SSL) are one lining taking the temporary and permanent loads—although this one lining may be built up in several passes. In most cases, a waterproof membrane is employed to provide a watertight structure (in CSL solutions this is generally between the primary and secondary linings).

Composite Shell Linings

Through recent projects, such as A3 Hindhead road tunnel[3] and Thames Water Hampton shaft, all in the UK, the use of sprayed waterproof membranes have given engineers an opportunity to explore the benefits of a composite shell lining, i.e. a sprayed permanent primary lining, sprayed waterproof membrane, and a sprayed secondary lining, where the primary lining acts compositely and takes a proportion of the long-term ground loads. A key step that had facilitated this leap forward has been omission of lattice girders and the use of laser profiling systems to control the shape of the tunnel during construction.[3] Lattice girders are usually not regarded as structural members, but they have been seen as essential in controlling the shape of the tunnel. They are notoriously difficult to spray around and leaks—and therefore corrosion—often occur at the location of the lattice girder. Removing girders removes both a corrosion problem and also reduces the need for men to work at the face when the full support is not in place.

Composite linings are now being incorporated into major UK projects, typically under the following design conditions, as shown on Fig. 3:

- 100% ground and hydrostatic loads applied to primary lining in the short term;
- The option of load sharing for the ground loads in the long term;
- Full hydrostatic load applied to secondary lining in the long term; and
- No bond or shear capacity between linings is used in the structural design.

This design methodology has resulted in some reductions to the thickness of the secondary lining when compared to conventional DSL, but this is fundamentally limited by the assumption that the water pressure acts on the membrane. For a shallow tunnel in soft ground, the water load is similar or even exceeds the ground load. The percentage of ground load on the secondary lining is usually determined from numerical models and

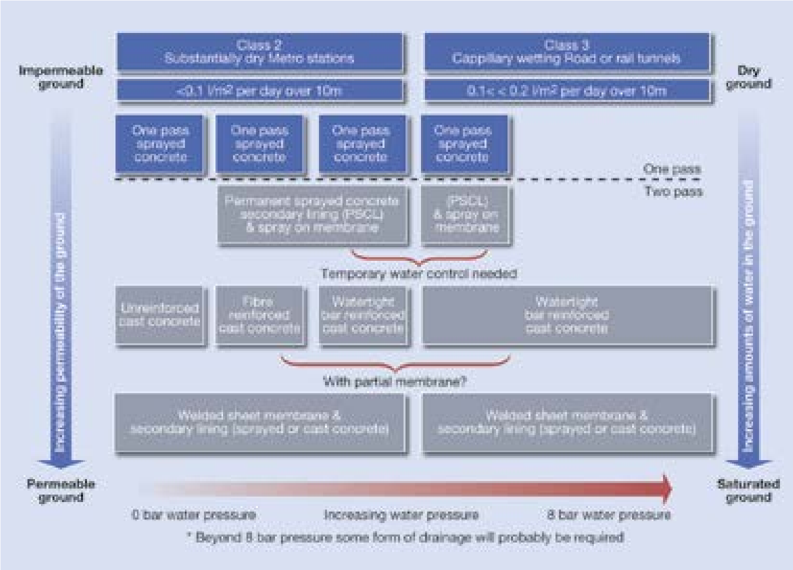

Fig. 1: Design options for linings and waterproofing[1]

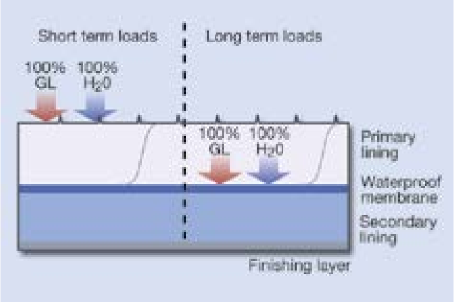

Fig. 2: Typical double shell lining

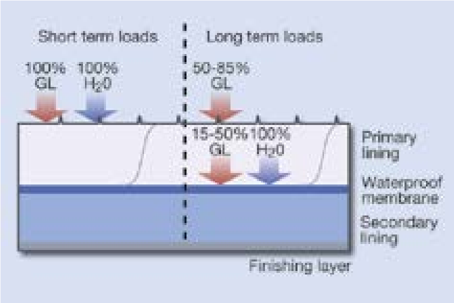

Fig. 3: Typical composite shell lining (partial composite with no shear or adhesive bond)

it varies depending on the loading behavior of the ground. In materials such as clay, there is a distinct short- and long-term behavior, while in others there may be little or no change in the loads over the lifetime of the project from the loads generated during the construction period. In other words, without some consolidation or rheological behavior in the ground, the secondary lining may not experience much of the ground load.

In one recent project, the first layer of sprayed concrete—the so-called sealing layer of 75 mm (3 in.) sprayed concrete—is regarded as temporary and omitted from the design in the long-term. This was due to concerns over sulphate attack and poor quality when spraying on to the excavated surface.

Presently, there is further study and testing being undertaken to demonstrate a fully composite lining as discussed later, and as shown in Fig. 4, i.e. shear and bond strength at the interface of the waterproof membrane. Once this is ascertained, further reductions could be achieved for the thickness of the secondary lining.

Figure 4 shows composite action between linings by achieving shear capacity across membrane-concrete interfaces:

- Load sharing for the ground load and water load (WL) in long term;
- Full hydrostatic load applied to secondary lining in the long term;
- Bond strength on membrane interfaces to be 1 MPa (145 psi); and
- Shear strength on membrane interfaces to be 2 MPa (290 psi).

The advantage, as discussed above, is the reduction to secondary lining thickness without compromising the water tightness requirement. The main disadvantage is there is currently no precedence for a fully composite lining with a spray-applied membrane. However, single shell permanent sprayed concrete linings have been successfully used on a number of projects such as Heathrow Terminal 51,[4,5] and the design for Hindhead considered both load cases—with and without full composite action.

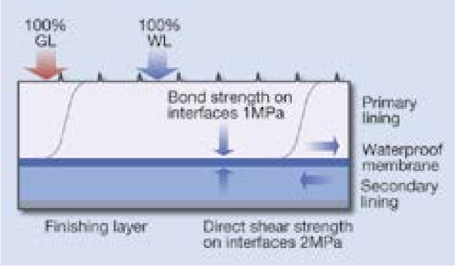

Fig. 4: Fully composite shell lining

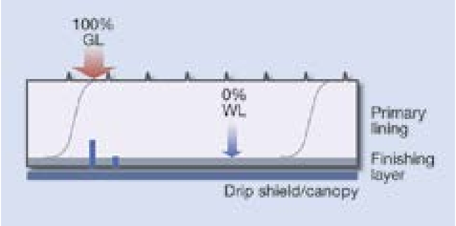

Fig. 5: Typical single shell lining

Single Shell Linings

Single shell linings (SSLs) offer the most efficient lining design (in dry or largely dry ground) as they take both the temporary and long-term loads and the construction is very fast compared to a double shell or composite lining where there are both primary and secondary lining stages to the construction (refer to Fig. 5). SSLs have been widely used in the hydropower sector and in all tunneling sectors in certain countries, most notably Norway:

- No waterproofing membrane;
- Ground loading all on primary lining;
- No hydrostatic load;
- Watertight concrete design, but allows local seepage; and
- Optional drip trays provided outside architectural cladding.

The main disadvantage is that clients will tend to opt for watertight tunnels, thereby avoiding operation and maintenance issues and drainage systems. Unless the ground is dry or generally impermeable—such as London Clay—it is hard to achieve watertight tunnels with SSL. That said, this can still remain as a design option for non-public tunnels where lower levels of water tightness are acceptable.

Composite Shell Lining—Design Philosophy

For recent projects, there has been a push to mechanize sprayed concrete lined tunnel construction as much as possible and thereby remove tunnel operatives from the face of the tunnel, decreasing the risk of death or injury as a result of tunnel collapse; being hit by falling sections of the newly sprayed lining ("sloughing"); or risks associated with fixing reinforcement, lattice girders, and sheet waterproof membranes at height. Therefore, with the precedent set from the A3 Hindhead tunnel construction, the lining design of sprayed primary and secondary linings with steel fiber reinforcement (SFR) and shape control techniques that remove the requirement for lattice girders and a sprayed waterproof membrane has been adopted for major SCL works in the UK where geological conditions are suitable. At present, little guidance exists on this subject so the features of this composite lining design are described in more detail as follows:

Primary lining—The permanent primary lining is designed to take the full short-term applied ground load and any other loads, such as compensation grouting and surface surcharges, expected in the 2 to 3 years prior to secondary lining installation. Any additional long-term loads, such as consolidation or creep in the ground, will be shared between the two linings, subsequent to the installation of the secondary lining. The loading is determined using sophisticated numerical models.

The primary lining is designed as a sprayed concrete lining containing structural fiber reinforcement. The structural fibers are to increase the ductility of the concrete and provide toughness and post-crack resistance in the long term (see Reinforcement section). Conventional bar reinforcement is only required at openings and some headwalls. Smaller diameter bars (typically less than 12 mm [0.5 in.]) can be encased fully in sprayed concrete without too much difficulty. Larger bars (up to 25 mm [1 in.]) have been used successfully in permanent sprayed concrete. Nevertheless, the concept is to minimize the corrosion risk by removing and limiting bar reinforcement wherever possible. The use of laser survey shape control has been a critical step forward as explained earlier, since it has removed the major corrosion concern of lattice girders.

The use of fiber reinforcement and the specification of durable sprayed concrete constituents ensure that the lining will retain its strength and durability properties in the long term and so all but a small thickness of the primary lining is load bearing throughout the design life of the structure. The initial layer of 75 mm (3 in.), which is sprayed directly against the ground, is considered as sacrificial and omitted from load capacity calculations in the long-term.

Typically the strength requirements for the sprayed concrete is C32/40 (i.e. a minimum characteristic cylinder strength of 32 N/mm² [4600 psi]), but measured at 90 days. The same concrete should achieve 28 N/mm² (4000 psi) at 28 days and exceed a modified J2 curve in the first 24 hours (as per EN 14478). The reduced strength at 28 days was deliberately chosen since it is known that, with modern accelerators, a high cement content is needed to meet the early age strength requirements and the concrete will continue to hydrate beyond 28 days. If a too-high 28 day strength is set, then the concrete will "overshoot" this considerably in the long-term, and the high strength introduces a new set of problems related to brittleness and underperformance of the fibers.

Secondary lining—Taking into account the loads and stresses already taken by the primary lining, the secondary lining is designed to carry:

- The full, long-term water pressure (see Improvements section);
- Internal loads, such as mechanical and electrical equipment;
- Part of the long term ground load; e.g. the effects of consolidation;
- The effects of temperature and shrinkage; and
- The effects of degradation of the primary lining (the sacrificial initial layer).

The proportion of ground loading applied to the secondary lining has been calculated using numerical modeling methods as the proportion of load carried by each lining will potentially differ, depending on the combination of geological conditions, the sequence of construction, and the lining system. Due to uncertainties over the mechanical properties of the bond between the membrane and concrete, the conservative working assumption is that there is no shear or adhesive bond at this interface. Obviously, this limits the ability for the linings to share the loads, particularly the assumption of "full-slip" on the interface.

Analyzing the effects of composite action is more complicated than it might appear at first sight, since in cases of uneven loading the behavior varies around the lining. Figure 6 shows how the loads in the secondary lining can vary depending on the shear properties at the interface, for a simple model of a circular tunnel under uneven loading.[9] Even under a relatively extreme combination of horizontal and vertical loads on a tunnel lining, no debonding in the normal direction was found, so this suggests that the adhesive bond is only important in the temporary case during the spraying of the secondary lining. In the course of other design calculations, it has been found that the percentage of ground stresses

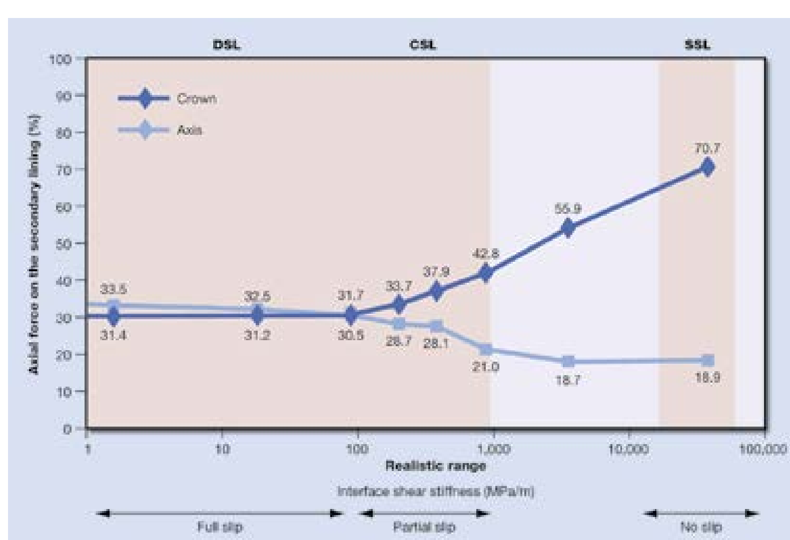

Fig. 6: The hoop load in a secondary lining vs the shear stiffness of the interface with the primary lining[9]

carried by the secondary lining varies from 15 to 50%. This is a function of the ratio of horizontal to vertical stresses, the lining thicknesses, and the tunnel shape, as well as the interface properties. The load-sharing is less pronounced in the design models for real tunnels because of the interaction with the ground; notably, the tendency for the stiffer CSL lining to attract more load overall but at the same time less is applied to the secondary. The loads in the primary tend to remain broadly similar but the reduction of bending moments in the secondary lining of up to 20% could permit a thinner secondary lining.

The secondary lining will be structural fiber-reinforced sprayed. Bar reinforcement is generally required at openings and some headwalls.

Secondary linings are typically designed to carry sufficient residual capacity to resist ground loading after a EUREKA time/temperature fire curve, as defined in the Technical Specification for Interoperability–Safety in Railway Tunnels (TSI-SRT). The EUREKA curve has been developed for the rail industry in Germany and is considered the most appropriate to the predicted fire scenarios. The secondary lining concrete (cast in-situ or sprayed) will contain micro-synthetic fibers in order to limit explosive spalling and maintain structural integrity. The quantity of fibers is typically determined by pre-construction testing and a dosage of about 1 kg/m^3 is normal. It has been shown in extensive fire testing for projects, such as Heathrow Terminal 5, A3 Hindhead, and CTRL, that the inclusion of micro synthetic fibers in high-strength, low-permeability concrete mixtures significantly reduces the risk of explosive spalling when exposed to severe hydrocarbon fires.

Waterproofing systems—Spray-applied waterproofing membranes have been selected due to the benefits they can offer by bonding to both the primary and secondary linings. This property is advantageous as it offers maintenance and repair benefits in the long term by preventing the movement of water, either behind or, should it be breached, in front of the membrane. Should a leak be found on the surface of the secondary lining, as water is not able to move laterally, the source will be easily located and treated at that location in the primary lining also.

In water-bearing stratigraphy, such as the Lambeth Group or River Terrace Gravels in London there is still a tendency for Clients and Designers to opt for a sheet waterproof membrane. Sprayed concrete can be applied to sheet membranes—for example: Thames Tunnel, UK; Russia Wharf, Boston, USA; or Dulles Airport, USA.

Reinforcement—Reinforcement of the linings will be provided by structural fibers in the sprayed concrete matrix in combination with steel bar reinforcement located around junctions and openings. Fibers—steel or macro-synthetic—add a modest tensile capacity. This can be incorporated into the design using a simplified stress block, for example, as described by RILEM[8] and shown in Fig. 7. Various design approaches have been adopted on different projects, partly reflecting the confidence of the client or designer, as much as the state-of-the-art. Traditionally, Design approach 1 was used and no benefit from the fibers was assumed. Clearly this is incorrect and unduly conservative. In Design approach 2, the fibers are seen as guaranteeing the inherent tensile strength of the concrete. This approach offers little benefit in design since the tensile capacity up to first crack is so small. The approach adopted most recently is Design approach 3, in which a simplified stress block, with a value of 0.37 fctm.fl, is used, based on RILEM.[8] This is conservative itself, because the stress at first crack is 20% higher than this value, which corresponds to the residual value at the end of a standard beam test. RILEM[8] recommends limiting the strain to 2.5%; the strains in a standard 75 mm (3 in.) beam test are higher than this at a deflection of 2 mm (0.08 in.).

In practice, the Ultimate Limit State does not necessarily govern. Crack widths in the lining should be less than 0.3 mm and this curtails the contribution of the fibers to tensile capacity under Serviceability Limit State conditions. The subject of crack widths still requires some development. Methods are suggested for predicting crack widths (such as in RILEM[8]) but naturally, because this is a new material, the spacing and development of cracks within fiber-reinforced concrete is not as well understood as in conventional bar reinforced concrete.

In the past, specifications have often prescribed a dosage of fibers; for example, in permanent linings, typically 30 to 40 kg/m^3 (50 to 67 lb/yd^3) of steel fibers. This is at odds with the normal practice in most other areas of setting performance specifications. Following the style of RILEM, sprayed concrete can now be specified in the following manner:

C28/35 FL 1.7

This means the 28-day cylinder strength should be 28 MN/mm^2 with a flexural tensile strength of more than 1.7 MN/mm^2 at a strain of 2.5%, which corresponds to a central deflection of 3 mm (0.1 in.) on the standard beam test. EN 144876 offers another alternative:

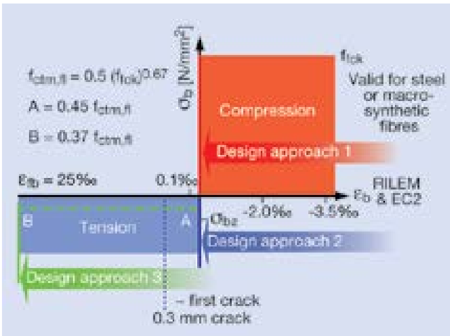

Fig. 7: Simplified stress-strain models for fiber reinforced concrete

C28/35 S 1.7 D 3.0

This should be modified to add defining the limits to one decimal place. Using whole numbers is simply too coarse a categorization.

For large bending moments, steel bars remain the only realistic option. At this point, it is worth mentioning that, on one recent project, a conscious decision was made to minimize the bending moments in the linings by adopting tunnel cross-sections that are almost circular, rather than adding bar reinforcement. The other possibility is to use thicker linings. Spraying some extra concrete is simple and quick, and therefore the saving in time and materials compared to adding bars outweighs the additional cost of the extra concrete. This also minimizes the exposure of workers to activities near the tunnel face where the ground is only supported by the initial layer.

A fierce debate is raging between suppliers of steel and macro-synthetic fibers. The promotion of the virtues of their own products is natural and healthy competition. However, some of the negative marketing is less helpful to designers and constructors. Both products have strengths and weaknesses. The latter—most notably, corrosion of cracked sections for steel fibers and creep for macro-synthetic fibers—deserves to be examined in detail dispassionately. Macro-synthetic fibers are a viable alternative and the issue of creep is unlikely to be relevant at the low stress levels that are inevitable when normal factors of safety are applied. Similarly, the necessity to limit crack widths and the benign environment in most tunnels means that corrosion of steel fibers is unlikely to be a significant issue. As a final remark, one should be careful of extrapolating the results of standard beam tests—where there is limited opportunity for load redistribution—to tunnel linings, which, in statically terms, are highly redundant shells which can redistribute loads very effectively.

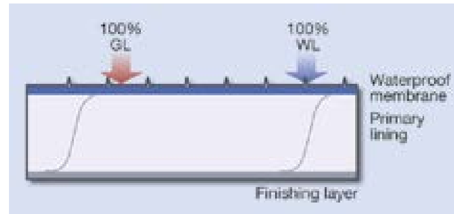

Fig. 8: Single shell lining with waterproof membrane

Improvements

An obvious first improvement would be to use the bond strength of the spray-applied membrane in a fully composite shell lining (refer to Fig. 4). As discussed earlier, this would lead to more effective load sharing and a thinner secondary lining. Sufficient evidence exists for effective bonding on both sides of the interface at the membrane. Only a modest bond is required for full composite action and the performance of a product can be verified by simple tests.

The real Achilles heel of composite shell linings remains the position of the waterproofing layer, which is more or less in the center of the lining. A simplistic interpretation of this implies that, in the long-term, the first layer of sprayed concrete is saturated with water while the secondary is dry. The primary lining has joints at every advance length and, although in principle the concrete can be just as good here as anywhere else, in practice, cracking and water paths are likely to form. In turn, this leads to the conclusion that the water pressure in the ground is applied at the location of the waterproofing layer and that reinforcing bars—which might be needed, for example, at junctions—should not be placed in the primary layer as they may suffer corrosion. Both design assumptions are questionable, but a more elegant solution would be simply to place the waterproofing layer on the outside of the lining, directly against the ground (refer to Fig. 8).

This has the advantage that it fulfills client requirements for a waterproof tunnel and reduces the overall lining thickness as per the conventional SSL. The salient features are:

- Application of a waterproof membrane that also has ground support properties to provide safe entry to face and watertight primary lining;
- All ground and water loads act on the primary lining for the design life;
- Requires continuous connection of "super skin" membrane between construction rounds;
- During construction phase, any observed seepage through primary lining managed in

collection channel and brought down to an evaporative drainage channel; and
- The suitability of the membrane is dependent on the geology and technology available, for example, presently not suitable for water bearing stratigraphy such as sands.

Thin skin liner (TSL) or so-called "Superskin" products, such as Masterseal 865 or Tamseal, could fulfill the dual role of an initial sealing coat to provide safe access to the face before the primary lining is sprayed and the first line of defense against water ingress. This technology has been around since the 1990s and has been trialed in the mining industry as a structural support or, in coal mines, to prevent methane ingress. Yilmaz[10] contains a good review of various TSL products and their properties. 5 mm (0.2 in.) of "medium" strength TSL is equivalent to 50 mm (2 in.) of SCL, in terms of structural performance at 1 day old. Achieving a substantially impermeable layer on the extrados of the tunnel, outside impermeable permanent sprayed concrete, would obviate the need for a secondary lining. The primary lining would carry all water and ground loads in both the short- and long-term. If necessary, a finishing layer could be applied later for aesthetics or fire protection. This represents the ultimate solution in terms of efficiency and sustainability. Trials are ongoing to investigate the best technologies to achieve this.

Table 1: Typical sequence for a 6m diameter SSL tunnel (1 excavation round)

	Tunnel construction stage/description	Duration/ minutes	Total time/ minutes	Thin skin liner age (tunnel shell)/minutes
1	Excavate and muck one metre tunnel excavation round			
2	Spray thin skin liner sealing layer for tunnel circumference	10 – 15	10 – 15	
3	Spray thin skin liner sealing layer over tunnel face	5 – 10	15 – 25	10 – 15
4	Clean up and move out sprayer kit	5 – 10	20 – 35	15 – 25
5	Set up SCL spraying robot	5 – 10	25 – 45	20 – 35
6	Spray structural SCL layer			Approx 30

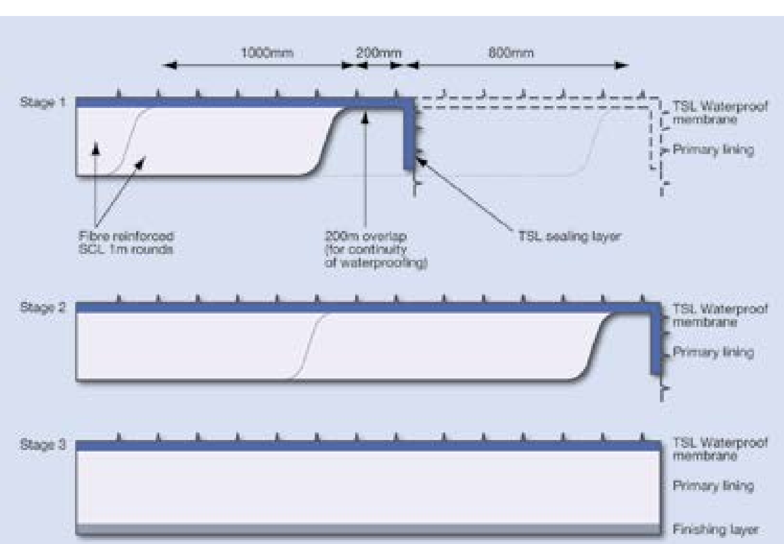

Fig. 9: Practical application of SSL

Single Shell Lining—A Practical Application

For a single shell lining, as described previously, to be a viable option (and thereby provide a significant saving to the lining cost), there would have to be a feasible construction method that would provide a watertight or near-watertight tunnel, i.e. a continuous waterproofing layer for sequential tunnel excavation and construction. If testing can demonstrate that sprayed concrete could be sprayed on to a partially cured, thin-skinned liner with a sufficient bond then the following sequence could be proposed:

Stages 1 and 2 show the proposed typical sequence of the single shell lining with the waterproof membrane sprayed against the excavated surface and acting as the sealing layer. The major difference with this methodology is that a 200 mm (8 in.) overlap is left to ensure that there is continuity in waterproofing between the 1 m (3.3 ft) rounds. Stage 3 indicates an application of a finishing layer. For a typical 6 m (19.7 ft) diameter tunnel, Stage 1, based on typical construction rates, could be broken down to the timeline shown in Table 1.

Therefore, the minimum curing time for the membrane/sealing layer unless construction is paused would be something in the order of 30 minutes.

Following discussion with BASF, it was proposed to carry out some initial testing of

> *"The minimum curing time for the membrane/sealing layer unless construction is paused would be something in the order of 30 minutes"*

spraying a thin skin liner onto excavated material and to spray some test panels to check that this method of construction is feasible and also provides structural bond requirements between the thin skin liner and the sprayed concrete, described next.

Testing

A shaft construction site in London, June 2011—With the assistance of BASF, the client, and the contractor, trials were carried out at the SCL shaft construction site in London in June 2011 in order to establish the effectiveness of spraying Meyco TSL 865 directly onto London Clay.

The test was conducted at the bottom of an existing shaft on freshly excavated material beneath the overhang of the sprayed concrete shaft lining. The ambient temperature during the trial was between 13 and 15°C (55 and 59°F). The surface onto which the TSL was sprayed consisted of London Clay, which had been excavated using a bucket with teeth. No dressing of the teeth marks had taken place.

The surface was good enough to be sprayed onto without additional preparation. For rougher surfaces, applying a 25 mm (1 in.) smoothing mortar might be required. The TSL cured well and was successfully sprayed over with sprayed concrete.

Hagerbach test panels, July 2011—Encouraged by the success of the initial trial, more testing was proposed to test the capability of both Masterseal 345 (sprayed membrane) and MEYCO TSL 865 (thin skin liner) for early strength and bonding to freshly sprayed concrete at early curing ages.

Three test panels were prepared at the Hagerbach testing area in Switzerland:

a) A layer of Masterseal 345, measuring 4 mm (0.15 in.) thick was sprayed onto Test Panel 1 with a dry sprayed concrete mix sprayed onto the membrane after it had cured for just over 30 minutes;
b) A layer of Meyco TSL 865, measuring 5 mm (0.2 in.) thick was sprayed onto Test Panel 2 with a dry sprayed concrete mix sprayed

> *"For soft ground tunnels, the traditional approach of a temporary primary sprayed concrete lining is very wasteful and, with current technology, unnecessarily conservative"*

*Table 2: Possible lining thicknesses for different lining options**

Lining option	Sealing layer	Primary lining	Secondary lining	Total
DSL	75 mm	325 mm	350 mm inside a sheet membrane	750mm
CSL-no bond	75 mm	325 mm	300 mm inside a spray-on membrane	700mm
CSL-bonded	75 mm	325 mm	250 mm inside a spray-on membrane	650mm

*This refers to a large diameter, shallow tunnel in soft ground

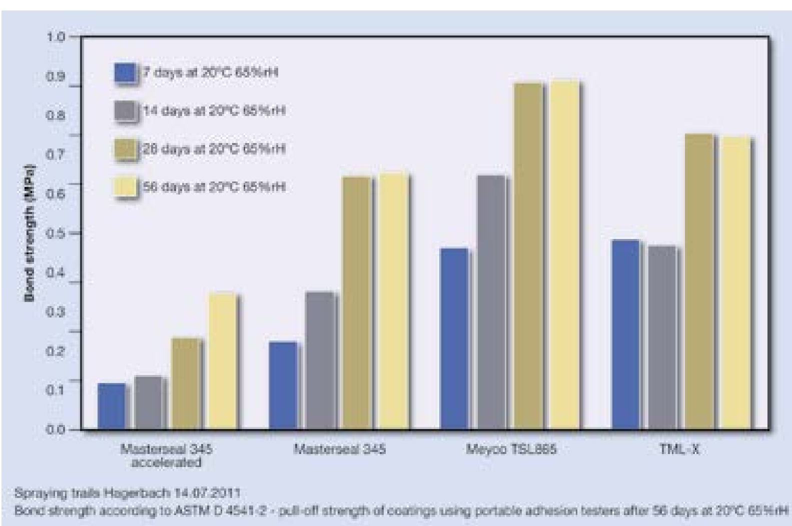

Fig. 10: Bond strength vs. age from Hagerbach trial

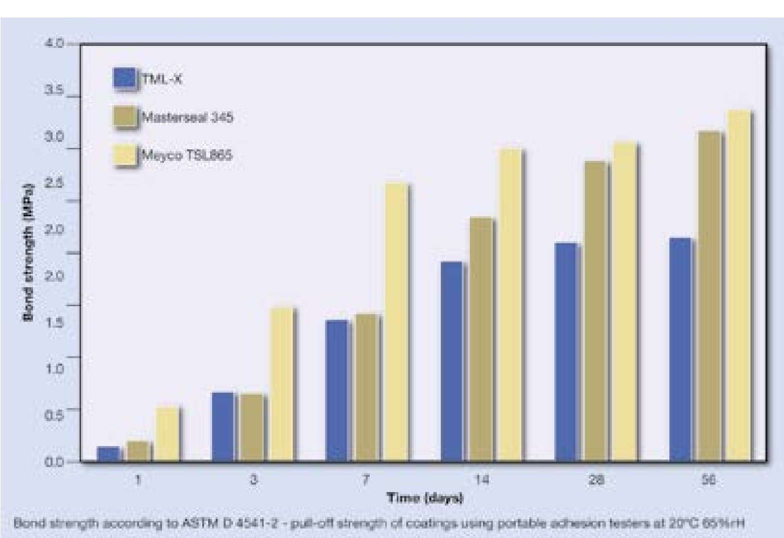

Fig. 11: Bond strength vs. age under laboratory conditions

onto the membrane after it had cured for just under 30 minutes; and

c) A layer of Masterseal 345 (accelerated), measuring 4 mm (0.15 mm) thick, was sprayed onto Test Panel 3 with a dry sprayed concrete mix sprayed onto the membrane after it had cured for just under 20 minutes.

Results—From the three test panels at Hagerbach, the following results for bond strength were obtained:

The tests showed that good bond strength can be achieved with spraying concrete onto relatively young sprayed membrane, particularly the Meyco TSL 865 (refer to Fig. 10). The latter could be classified as a "medium" strength TSL, according to Yilmaz's groupings.[10] While further testing would be required to prove that this could be achieved on a regular basis, this opens up the possibility for a single-shell tunnel lining with sprayed membrane/sealing layer or mortar followed by a sprayed membrane and then the sprayed concrete structural lining.

Discussion—The trials carried out on-site, spraying the TSL 865 onto London Clay, demonstrated that a single shell should be considered successful, and that a progressively strengthening bond was achieved between the TSL and the London Clay even though the conditions were not conducive to rapid curing.

The testing carried out at Hagerbach demonstrated that a bond can be achieved between the waterproof membrane and the sprayed concrete after a minimum curing time of the waterproofing membrane of 30 minutes. In comparison with what can be achieved under laboratory conditions, as shown in Figure 11, it is clear that further optimization of this process is possible, and further testing of this process should be carried out in particular to determine:

- Optimal curing time of the thin skin liner to achieve an acceptable bond strength to the sprayed concrete compared to construction sequence requirements;
- How accelerators affect curing time of the thin skin line compared to bond strength achieved with the sprayed concrete; and
- Whether an alternative product could be developed that could be optimized to fulfill both the sealing layer and waterproofing properties.

Conclusion

For soft ground tunnels, the traditional approach of a temporary primary sprayed concrete lining is very wasteful and, with current technology, unnecessarily conservative. Over the last 15 years, a series of pioneering projects in the UK has revolutionized the design and construction of sprayed concrete linings. There is a growing acceptance of the use of sprayed concrete as permanent works, as well as spray-applied waterproofing membranes. In turn, this has generated a body of experience on real projects which has been fed back into the design methods and technology. While composite permanent sprayed concrete linings may not be suitable for all cases, there are many where this approach is very effective. Table 2 illustrates how the lining thickness could be reduced by using spray-on membranes and the composite action of all parts of the lining. As noted before, some key design assumptions limit the savings in materials for CSLs, although there are still significant savings in the costs of formwork and the time to install. The biggest savings are offered by using the SSL option. Some design issues remain and Mott MacDonald is involved in ongoing research in the field of fully composite linings.

Acknowledgments

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Since starting as a fresh graduate, he has moved on to lead design teams, supervise construction, and manage projects with a construction value of hundreds of millions of euros. On the way he has gained hands-on experience of many forms of tunnel construction, been involved in research projects, and participated in all stages of design development.

Thomas has given lectures at the British Tunnelling Society course, the Budapest Technical University, and the Danish Technical University. A regular contributor to magazines and conferences, with more than 50 publications, he has written articles on subjects ranging from sustainability to user-friendly contracts. A Chinese version of his book, Sprayed Concrete Lined Tunnels*, is under production and an update of the English version is planned. Thomas is a member of the ITA's Working Group 12 on Sprayed Concrete and he has just joined ITAtech's design group.*

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Success in Shotcreting Begins with Forming

By James Scott

In the creation of swimming pools, forming is one of the core components to building a successful shotcrete structure, and can be done in a variety of ways. Each type of forming has its pros and cons; and there usually is more than one type of forming that will work for any particular situation.

Forming for shotcrete is one-sided and has performance criteria it must meet. Stability of formwork is a major factor that allows for successful shotcreting. Form stability means forms that don't move or vibrate during the gunning process, and allows fresh shotcrete to be placed at optimal density without shifting in the finished concrete structure. Consistent high density of the placed shotcrete equates to water tightness of the pool shell, which is the whole point, after all!

Often, earth is used as the form for shotcrete in two areas: horizontal and vertical (that is, floors and walls).

- Most pools will have the floor setting on the in-place soil of the project. It is a basic, but fundamental, requirement that all organic soil and materials must be removed, with the subgrade the pool floor rests upon left in an undisturbed and compact condition (Fig. 1). Many times, a layer of crushed stone is applied over the top of the subsoil to provide a dry, stable workable surface, as well as a clean, dense surface for the shotcrete. The crushed stone also serves as a drainage layer under the pool shell. In sites with a rock subgrade, the crushed stone creates a "cushion" over the rock. An additional benefit of the crushed stone layer is that it can be used to fill in voids or remove unevenness in the excavation process—which enables the floor to be shotcreted at a uniform thickness to meet the design thickness, as dictated in ACI's "Shotcrete for the Craftsman."
- In addition to being a form for the floor, the earth subgrade has to structurally carry the high loads of the filled pool without excessive settlements. The soil will be looked at for various issues when analyzing its suitability for any particular project: soil structure and variation in the soil profile, presence of groundwater, ledge rock, expansive soils, and sloping grades. The geotechnical engineer will often use soil testing to determine the soil's competence to carry the loads. The structural engineer will consider the bearing capacity and settlement of the soil.
- I once asked an engineer, "What is the single most important thing I could focus on to lessen my risk when building a pool?" His answer was simple and telling; he simply said, "Compact the last layer of soil exposed by the machine before putting down the crushed stone." This told me that if I left any disturbed, less-dense soils under my pool, compaction would be taken care of for me by gravity with the weight of the filled pool! In a very real way, the ground must be in a stabilized, compact condition before the shotcrete process. For those in the freezing areas, be aware that a frozen subgrade has an expanded volume that

Fig. 1: The subgrade has been carved to the profile required, including trenching of plumbing lines beneath the future pool shell

will subside when thawed, and should not be shotcreted upon.

In areas with relatively stiff soils, earth can also be used as the one-sided form for the walls of the pool (Fig. 2). Historically, the residential pool has been formed in exactly this way, as an efficient means to construct a pool within the reach of the burgeoning middle class. This process can be quite effective, as it requires less time and materials spent excavating and forming, with little backfill. It does, however, require an excavator and dig crew who are experienced in this practice. Again, loose, soft, or fractured soil should be removed to give the shotcrete a solid receiving surface. Loose sands would not be appropriate for forming pool walls because they cannot stand up to create a vertical surface to shoot upon.

Other materials are commonly used for the one-sided forming of the walls. If a material is able to be shaped, and is durable and not detrimental to the shotcrete process, it probably can be used. Rough-cut lumber, framing lumber, pegboard, plywood, and Steeltex® are among these materials; and many times, more than one material is used to allow creation of curves and add stability to the form.

Forming materials are used instead of earth for various reasons. The soil may just be too rocky, leaving large voids and caved-in walls during excavation. The structure may be built above existing site grades due to design choices or building on sloping land (Fig. 3). In some cases, pools are excavated without the earth forming crew being on site, requiring forms to be built later.

The forms must be constructed in such a way as to provide a solid, stable, nonvibrating surface for the shotcrete. Once you realize that shotcrete is being shot out of the nozzle at up to 180 ft/s (55 m/s), you start to understand the need for form strength. Ironically, should the forms be weak or loose, the shotcrete crew may try and reduce the amount of compressed air being delivered, so as to “save” the form. But, in doing this, they fundamentally alter the shotcrete process with a detrimental effect on the in-place quality of shotcrete in the finished project. In some areas, the forms must also be strong enough to carry the static weight of the wet shotcrete once in place. A sloping wall or the bottoms of skimmer boxes are two examples that come to mind.

Steeltex deserves special mention. Steeltex is a brand name for a thick-gauge welded wire mesh covered with a heavy-duty fiberglass/water-resistant paper. It is commonly used in swimming pool forming and works well for creating curved profiles. An incorrect practice occasionally seen is to install a wood form for the pool beam (top of pool wall), hang the Steeltex down from the wood form, and then simply tie the Steeltex to the steel reinforcing cage with wire, but with no other support (Fig. 4 and 5). As gunning occurs, the impact and weight of the shotcrete pulls on the reinforcing bar and the wood forms above. This incorrect support of the Steeltex leads to poor shotcrete practice as the crew tries to save the forms by adjusting the shotcrete flow, which can

Fig. 2: The rocky soil has been trimmed to accept the shotcreted pool shell

Fig. 3: A significant set of wood forms, well-reinforced, for a negative-edge pool being built above grade

Fig. 4: Short pegboard forms poorly supported with undersized staking allows for movement at the top of forms during shotcreting

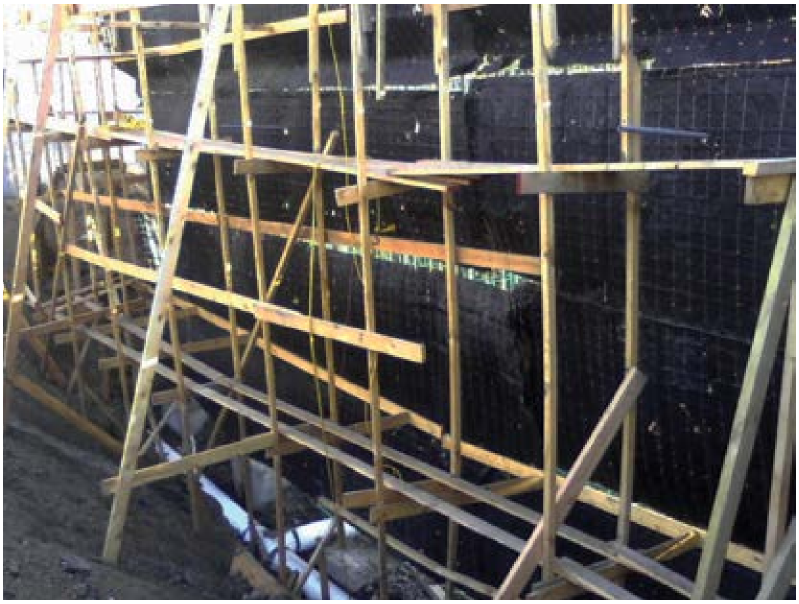


Fig. 5: A 13 ft (4 m) tall pool wall with Steeltex® hung haphazardly, with a terrible lack of support by undersized and insufficient wood forms

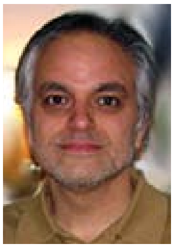
Fig. 6: Steeltex forms properly set with overlaps, wood staking behind, and plywood ribs attached to the front


Fig. 7: Proper Steeltex forming allows the shotcrete crew to focus on their placement and finish details

possibly lead to catastrophic failures during the shooting. Steeltex in itself is not bad; it simply needs to be supported with appropriate amounts of stakes, ribbing, or other forming materials (Fig. 6 and 7).

Many times, forms must hold up to extended weather and occasionally even over the winter. On complex or large pools, there may be weeks and months between forming and shotcreting, as plumbing and reinforcing steel placement take place, as well as the coordination of other work going on around the pool. In highly regulated areas, pre-shotcrete inspection schedules and building department requirements can add a great deal of time. Forms get rained on, knocked around by other trades on the job, and get snowed upon. We've even had to disassemble portions of tall forms on a negative-edge pool when high winds were forecast. So, projected timing, exposure to the elements, and job-site activity must also come into play when choosing materials.

To my way of thinking, gaining knowledge and a technical understanding of the shotcrete process is the best way to determine and understand the needs of the forming phase. As you come to understand what's happening during shotcreting and the magnitude of forces that come into play, it leads to a realization of the vital role that forming has in the success of the process and encourages appropriate techniques.


James Scott *is a third-generation Watershape Designer and Builder who has worked in the swimming pool and landscape industries for 39 years. He received his BS in business and accounting from Southern Methodist University, Dallas, TX. Through Group Works LLC, Scott has aligned himself with Genesis 3 and other organizations that focus on continuing education and increasingly higher standards in the watershape industry. He is a Platinum Member of Genesis 3 and a certified member of the Society of Watershape Designers. Scott is also an APSP-Certified Professional Builder and an ASA member and has trained with the Portland Cement Association. Scott and Group Works LLC have been featured in regional and national publications.*

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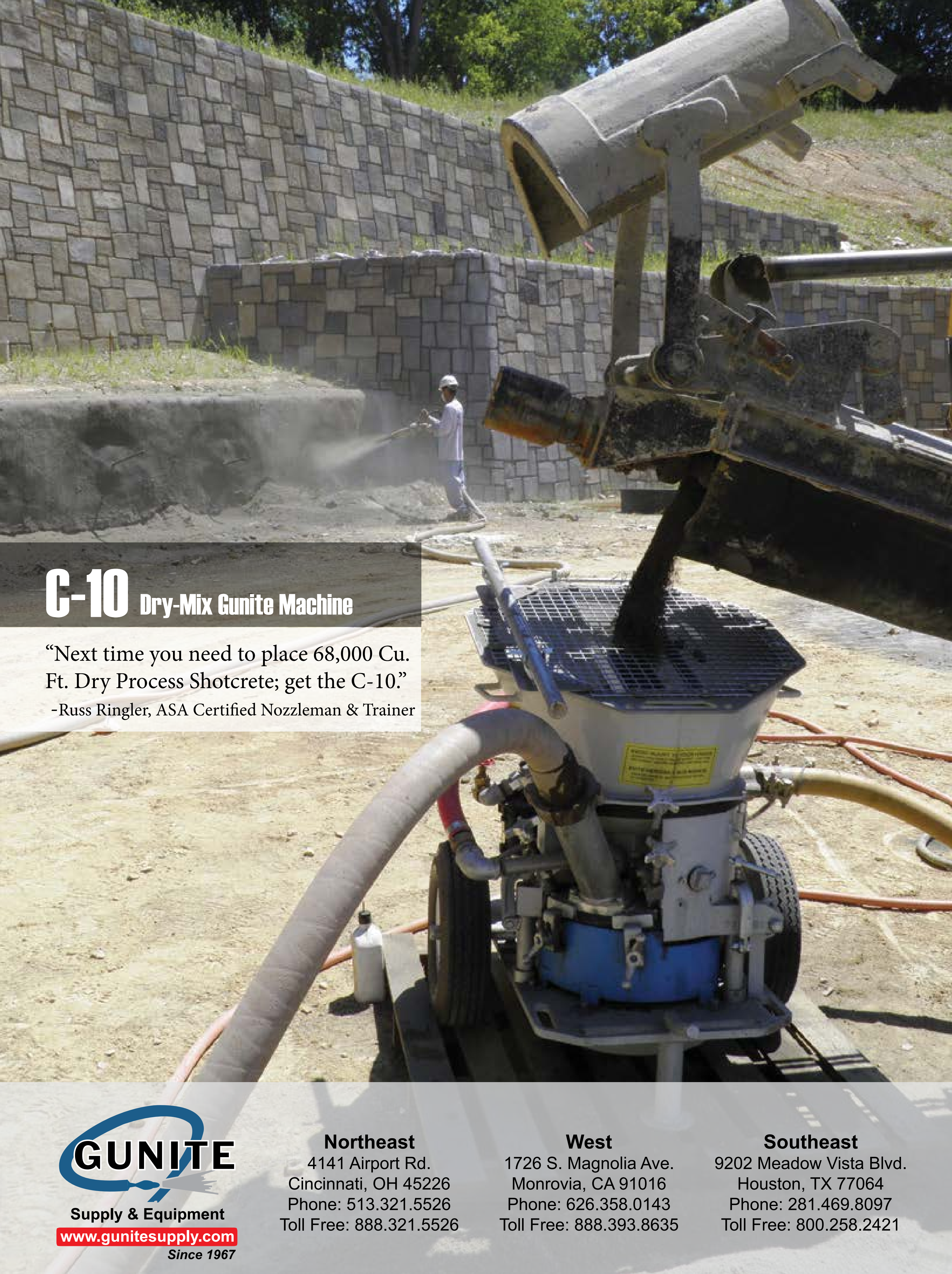
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The Clamp That Failed

Job-Site Safety is More Than a Hard-Hat Sticker

By Derek Pay

The shotcrete world can be dangerous. A few summers ago, I was on break beside the wet-mix shotcrete pump during a long day of nozzling. It was very hot. As usual, our projects require layout of a considerable amount of 4 in. (100 mm) steel placement line—a routine task for our crew. We know that very high pressures are necessary to convey materials through long placement systems and we prepare them carefully. Between loads, the pump operator advanced the material a few strokes. The pump strained, and unexpectedly, a large clamp failed, and the system burst. I had been cleaning my safety glasses and had no eye protection. I was blasted by shotcrete in the face with incredible force and was extremely lucky to not damage my face or eyes.

You never know when unforeseen accidents may happen. This was a reminder of the importance of safety requirements. As the proverb goes, "better a thousand times careful then once dead," and safety doesn't happen by accident.

A little over 3-1/2 years ago, our company acquired a small local shotcrete company from the Salt Lake City, UT, area to complement our shoring division. The acquisition included specialty placement equipment to complete smaller projects such as swimming pools, small shoring walls, and seismic upgrades. Over time, we have invested in more equipment, man power, and training to allow our company to satisfy this region's diverse shotcrete needs. Our scope of work includes stamped architectural shotcrete walls, soil nail walls, shoring, underground parking structure walls, seismic upgrades, shotcrete tunnels, canals, and carved rock features.

Our company's "learning curve" from mainly residential work to larger-scale projects has been challenging, and requires us to be compliant with all shotcrete safety rules and regulations. We have also been subject to specific safety requirements from multiple general contractors. Many of these contractors go above and beyond OSHA regulations to maintain a safe working environment for everyone on the job. It has been a trying task coming from a small "Mom and Pop" shop and transitioning into the world of commercial construction.

In early 2012, we hired an outside consultant to help us refine our shotcrete placement division. After setting up our equipment for a shotcrete placement mockup, he noticed safety errors that could potentially cause damage. He spoke to us about safety issues and legal ramifications that can arise when safety oversights occur. It became clear that many accidents are not accidents, but preventable, through well-proven safe practices.

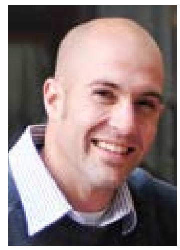
Unfortunately, many of us learn the shotcrete craft through experiences that have provided an acceptable outcome over time. Past employers, coworkers, and outside opinions influence nearly all decisions that must be made by the work crew daily. Many times, critical safety oversights occur

Fig. 1: The importance of safety in the shotcrete world: a 5 x 4 in. (125 x 100 mm) heavy-duty reduce fitting with broken heavy-duty ring

Fig. 2: Daily checklists are a must in preventing injuries. Heavy-duty clamp cracked at the hinge joint

because workers do not possess the risk-specific training necessary to make the right choices, allowing accidents to happen. The clamp that failed was not inspected for damage prior to its failure. Are yours? We have learned that adopting strict safety policies that mandate inspection of all pressurized components for wear, cracks, or damage can reduce, but not eliminate, hazard.

Since completing the class, we have implemented a daily safety checklist enforcing strict guidelines that improve worker safety. The checklist includes clamp checks, pinched rubber checks, reducer lining checks, nozzle cleanliness verification, whip checks, weekly "tool box" meetings, and a daily mechanics safety check on the shotcrete pump and air compressor. By doing this, we are taking the proper preventative care to minimize worker risk. Our safety program reinforces our commitment to maintain a safe work environment for everyone on the job site. Shotcrete can be dangerous work. Safety is far more than a compliance form and a hard-hat sticker. Knowledge is the first defense to safety. And as the proverb goes, safety shouldn't happen by accident.



ASA member ***Derek Pay*** *is Superintendent and Lead Nozzleman for Jones Shotcrete in the Salt Lake City, UT, area. Pay started in the pool industry 12 years ago and over the years has ventured into all phases of shotcrete, including structural walls, seismic upgrades/retrofits, overhead, shoring walls, faux rock, skateboard parks, water features, and anything else that shotcrete can do and will do in the future. Pay received his BA from the University of Utah. He is an active member of ASA and an ACI-certified nozzleman in wet-mix vertical and overhead.*

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Shotcrete Classics

Reprinted courtesy of Engineering News-Record*, McGraw Hill Financial, November 9, 1933*

Technical Editor's Note: The following article is reprinted from *Engineering News-Record*, published November 9, 1933—80 years ago! Reading the article gives a fascinating glimpse of the past in our shotcrete industry, but surprisingly hits on many of the fundamental aspects of shotcrete we still research today: nozzle material velocities, cement ratios and water content of mixtures, size and shape of test specimens, percentage of rebound, and air compressor size. Coincidently, in this issue of *Shotcrete* magazine, you'll find an article detailing current research on nozzle material velocities and another article that details the use of ground recycled glass in shotcrete mixtures, which finds its use helps to reduce water demand. I must admit I also felt a bit of nostalgia seeing the picture of the "latest improved CEMENT GUN" at the end of the article. It looks almost exactly like the double-chamber gun I operated on dry-mix shotcrete jobs in the late 1970s. And although the manufacturer has changed names several times, the same basic gun is still available today! Enjoy this blast from the past!

And here's today's model!

(N-2 Gun, photo courtesy of Putzmeister Shotcrete Technology)

New Test Data Aid Quality Control of Gunite

Tests conducted in relining reservoirs for Syracuse, N. Y., provide basic data on nozzle velocities, size and shape of test specimens, and cement ratio and water content of mixes

By E. P. Stewart
Dept. of Engineering, Division of Water, Syracuse, N. Y.

THE RATIONAL CONTROL of mixtures of hydraulic cement and aggregates has been extended by the development of basic data on the constitution and application of gunite. Extensive studies made in connection with the relining of two reservoirs of the Syracuse, N. Y., waterworks have given data of value on nozzle velocity, bulking of sand, cement ratio, water content, age of dry mix and strength. In particular, the study of the important factor of nozzle velocity has been extended to positive determinations of velocities for nozzles of different sizes. —EDITOR.

WOODLAND RESERVOIR of the Syracuse (N. Y) water supply is a kidney-shaped structure 1,737 ft. long and 406 ft. average width. At the maximum depth of water of 36 ft. it holds 125,000,000 gal. The side slopes are 1 on 2. It was constructed in 1892-'95. After a year in operation it was emptied and cleaned (1896), presumably to eliminate algae tastes. From that time it was never emptied again until 1932, when the relining work discussed in this article was undertaken. Based on successful results with the previously lined Westcott Reservoir (*ENR*, Nov. 19, 1931), a $1\frac{1}{2}$-in. gunite lining was adopted.

The original lining consisted of a 9-in. course of hand-mixed concrete on the bottom and up the slope to the berm. On the berm the concrete was thickened to 12 in., and on the upper slope it was 6 in. thick with a 12-in. paving of limestone laid in mortar. No construction or expansion joints had been provided; each day's pour of concrete had been joined to the preceding day's work in irregular lines without special effort to secure bond. An examination of the lining showed little actual concrete disintegration, but the concrete was quite porous. There were many separated construction joints and some settlement cracks. At the angle of the lower slope with the berm and the full length of the berm was a crack $\frac{1}{8}$ to $1\frac{1}{2}$ in. wide caused by settlement of the upper slope.

New lining

The necessity for relining came from a serious leak that occurred in January, 1932, at a point where the embankment is about 40 ft. high. As stated, a $1\frac{1}{2}$-in. layer of gunite was adopted. The reinforcement was 4x4-in. mesh, No. 7 galvanized and electrically welded steel wire. It was fastened to the old lining at regular intervals with $\frac{1}{4}$-in. expansion bolts. During the first part of the work the mesh was held up $\frac{3}{4}$ in. from the old lining by the nozzleman's helper while some gunite was shot under the wire at several points. Later, small stones about $\frac{3}{4}$ to 1 in. thick were put under the wires. Where the side slopes meet the bottom, an extra thickness of gunite was shot. This was doubly reinforced by lapping the bottom mesh over the slope mesh for 1 ft. or more.

Two types of expansion joints were used. At the inner edge of the berm (the edge nearest the center of the reservoir) the settlement crack mentioned above was cut out to V-shape and covered with a strip of mesh and a batten of gunite about 3 ft. wide, and mopped with hot pitch, which hardened to form a smooth, glossy surface. The gunite lining was placed continuous over this batten and pitch. Fig. 1 shows this construction, which allows for movement of the berm slab and slope lining beneath the gunite as the gunite lining floats on the layer of pitch.

Five expansion joints running across the bottom of the reservoir up to the berm, about at right angles to the center line, and one joint running longitudinally about midway between the sides were constructed, copper expansion stops and pitch being used. These joints, which were about equally spaced, did not run in continuous straight lines, as existing cracks and construction joints were taken advantage of as much as possible. Where neither joints nor cracks existed, a joint was formed by cutting through the old lining with an air hammer. Expansion joints in the gunite lining were constructed above these joints in the concrete, as shown in Fig. 2. The copper strips were soldered except where they crossed at right angles, when they were lapped, with a layer of plastic between them. These joints were difficult to make and required care and supervision to insure good construction.

It was decided to rent equipment and construct the new lining with city forces. The Cement Gun Co., of Allentown, Pa., was low bidder on the equipment. It furnished four compressors, two mechanics for operating the compressors and servicing all of the equipment, and two continuous dry mixers. The compressors had a displacement of 1,800 cu.ft. per minute. The actual free air delivered was measured continuously by means of an orifice in the main air line and a recording differential meter. It was found that the volumetric efficiency of the compressors was approximately 79 per cent. In addition, a city-owned compressor was used, making the total output of the plant 1,630 cu.ft. per minute. This amount of air was sufficient satisfactorily to operate four or five guns with $1\frac{1}{4}$-in. nozzles, depending on the use of the blow-down line, and five or six small pneumatic hammers for drilling.

Tests and inspection

A simple field laboratory was set up on the job, where daily tests were made to determine the moisture content of the sand as received and as used in the mixers, and the fineness coefficient and silt content of the sand. Continuous

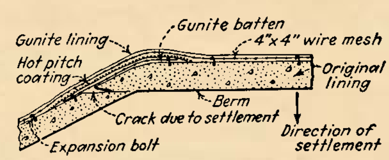


Fig. 1—Detail of expansion joint in gunite relining at angle of slope and berm of Syracuse, N. Y., waterworks reservoir.

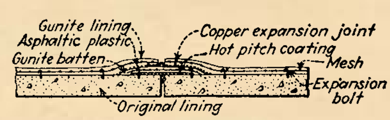


Fig. 2—Detail of bottom expansion joints in Syracuse reservoir, showing copper waterstop.

checks were made to determine the cement ratio in the mix. This was one of the principal routines of the laboratory, as it was found that the mix varied somewhat for a given setting of the mixers, depending on the moisture content of the sand and the manner of feeding the mixers. Daily checks were also run on the moisture content of the gunite shot. By means of these checks the average water content was controlled at each nozzle. This was found to be a highly important feature of the work, as the strength and density of the gunite varied greatly with the water content. Periodic tests were made to determine the moisture content of the rebound, the percentage of rebound and the cement ratio in the gunite. In addition, extensive experiments were conducted on nozzle velocities as a continuation of the study previously conducted at the Westcott Reservoir (*ENR*, Nov. 19, 1931).

Study of nozzle velocity

In connection with the Westcott Reservoir work, it had been found that there is an optimum velocity at which to shoot gunite Before work was begun on Woodland Reservoir, all of the guns were equipped by the city with the nozzle-velocity-measuring devices that were developed on the Westcott Reservoir lining job. The velocity at each nozzle was read at the gun by means of a single manometer and a suitably calibrated scale.

A velocity of 375 ft. per second was first used, as previous experimental work had shown this to be the most satisfactory velocity. Most of the previous tests, however, had been made with a $\frac{3}{4}$-in. nozzle operating with a N-0 gun. As $1\frac{1}{4}$-in. nozzles and N-1 and N-2 guns were being used on this job, several series of velocity samples were shot to determine the proper velocity to use with this larger equipment. The results of these tests showed that gunite of maximum strength and density was obtained with a velocity of about 425 ft. per second as read on the manometer scale.

After making this determination, opportunity was afforded of checking the manometer velocity scales used in all of the Syracuse work against accurate air-measuring standards, and it was found that these scales were in error, showing air velocities less than actually existed at the nozzle. Correcting for this error, the velocity of 425 ft. per second as read on the manometer scale becomes 510 ft. per second. (These velocities and all of the nozzle velocities mentioned in this article are expressed in terms of the cubic feet of free air per second supplied to the nozzle, divided by the area of the nozzle opening in square feet.)

Fig. 3 shows the average results of the velocity tests on the $1\frac{1}{4}$-in. nozzle, *corrected* nozzle velocity in feet per second being plotted as abscissas against compressive strength of gunite in pounds per square inch as ordinates. The graph also shows correct nozzle velocities for the average results of all of the velocity tests with the $\frac{3}{4}$-in. nozzle that were made in connection with the Westcott Reservoir lining and many more recent tests made with the same size nozzle. These velocities are applicable when the nozzle is held at a distance from the work of approximately 4 ft. for the $1\frac{1}{4}$-in. nozzle and 3 ft. for the $\frac{3}{4}$-in. nozzle.

Although no tests were made during the work with a 1-in. nozzle, subsequent tests made under actual working conditions with nozzle-velocity meters, where a 1-in. nozzle was used, developed values and results practically in accord with the $\frac{3}{4}$-in. nozzle, as shown on Fig. 3.

These curves show that a higher velocity is required when using a $1\frac{1}{4}$-in. nozzle than when using a $\frac{3}{4}$-in. nozzle. There are many factors which account in part for this, but it is probably due for the most part to the fact that there is a tendency to hold a large nozzle at a greater distance from the work than a small nozzle. In the former case a greater initial speed at the nozzle is required to obtain the same impact for a given particle of sand than in the latter. This is probably due to air friction. Tests showed that holding the nozzle close to the work has the same effect on the quality of the gunite as increasing the nozzle velocity, which means that lower velocities may be safely used on close-up work.

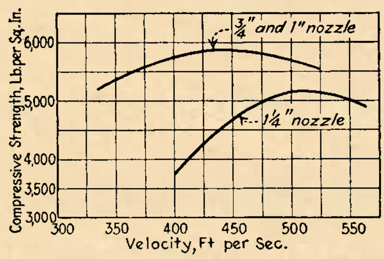


Fig. 3—Graph of compressive strength of gunite placed at various nozzle velocities with three sizes of nozzles, as determined by Syracuse tests.

It is probable that the velocity of the sand and cement particles impinging on the surface on which gunite is applied is not that of the air velocity obtained by dividing the air input to the bottom hopper of the gun by the area of the nozzle. The section area of the material and water leaving the nozzle varies with the output of material. Assuming a constant input of air, the nozzle velocity varies, increasing with an increase of material. The sand and cement particles, however, are slowed down between nozzle and work by the friction of the air. Then again the rubber liners of the nozzles wear, reducing the nozzle velocity for a given input of air as the diameter of the liner wears larger. The Syracuse tests were run under normal operating conditions, however, and should be typical and applicable for general use.

The velocities are expressed in terms of air input and of nominal nozzle diameters, as this seems to be the most practical method. On this basis the compressor capacities can easily be calculated for various-sized nozzles, adding 50 to 60 cu.ft. per minute of free air for the air motor on the gun. These velocities are based on free air at 60 deg. temperature at the nozzle.

Fortunately, a relatively large variation in velocity may be used without serious loss of strength and density. As shown by Fig. 3, the velocity, when using $1\frac{1}{4}$-in. nozzles, may vary from 450 to 550 ft. per second without serious loss of quality. Experience on this work showed that it was neither economical, practical nor desirable to shoot at higher velocities than 550 ft. per second. Velocities below 450 ft. are not recommended except where it is necessary to hold the nozzle close to the work.

Correcting for the error in manometer scale, the recommended operating velocities, as set forth in the previous paper on this subject, would be from 400 to 500 ft. per second for the $\frac{3}{4}$-in. nozzle. This would also be true for most work with a 1-in. nozzle. However, as both of these small nozzles are used extensively for close work, such as steel incasement, tunnel and sewer work, where it is sometimes necessary to hold the nozzle at about one-half the normal distance from the work, a velocity of 375 ft. per second is more advantageous and does not sacrifice quality on account of the nozzle distance.

As soon as the results of Fig. 3 were available, the average operating velocity was raised from 375 to 425 ft. a second, as shown on the manometer scale, the latter corrected being 510 ft. per second. Throughout the rest of the job a variation in velocity was not allowed of more than plus or minus 6 per cent of this value. As soon as the lower limit was passed, a gun running low was shut down and not put into operation again until the air supply had increased sufficiently to obtain the proper velocity.

This method of measuring and controlling the nozzle velocity was used successfully throughout the job. It was found that uniform velocity made for uniform production and operation of the guns.

The nozzle-velocity meter was also of further value in that it would indicate a tendency of the hose to plug, thereby warning the operator in advance so that he could cut down on his feed wheel in time to avert a complete obstruction. Moreover it was easy to determine which guns were using more air than necessary, whereupon they were throttled, making more air and pressure available for the guns that required it.

Preparing strength specimens

Tests were run at Woodland Reservoir to determine a practical size of gunite specimen that would be large enough to eliminate errors in determining the section area and yet small enough to be easily and readily shot, cut out and broken. The most successful method used throughout most of the job was to shoot a mound of gunite 4 in. thick and about 6 in. square at the base. When this sample had partially hardened, a specimen was cut 4 in. high and 4 in. in diameter. This was done by placing a 4-in. wooden cylinder on top of the specimen and cutting the gunite away with a trowel. The specimen was finally shaved to true cylindrical form by means of a half longitudinal section of a 4-in. steel pipe sharpened to a knife edge and equipped with a handle. The cylinder was used as a guide for the steel pipe shaver. A comparison test indicated that a sample of these proportions would give the same compressive strength as that of a specimen whose height was twice the diameter.

The results, in lb. per sq.in., of the

compressive strength tests on specimens on this work are as follows:

Average of 66 specimens 3 to 5 days old (majority 3 days)......	4,503
Average of 31 cylinders 5 to 14 days old (majority 5 to 7 days)......	5,111
Average of 6 cylinders 28 days old.	6,893

These samples were made with the regular sand used in the work, which, while not as hard as obtainable in some sections, was one of the most satisfactory available in the vicinity of Syracuse.

Bulking of sand

The nominal mix was 1 part of cement to $3\frac{1}{2}$ parts of sand measured by volume, sand containing 4 per cent moisture by weight being taken as the standard. Tests showed that the sand used bulked to the maximum when containing from 3 to 4 per cent moisture. With this moisture content the bulking action gave the sand 26.5 per cent more volume than in a bone-dry state. The amount of sand used in gunite was 6,430 cu.yd. This was measured in a semi-compacted state in the truck bodies as they arrived on the work. The moisture content averaged about 6 per cent. It was found that the sand bulked about 8 per cent from the truck to the storage pile, and that further bulking of 10 per cent occurred when the sand was dried out to contain about 4 per cent moisture. The total sand used on the basis of 4 per cent moisture was therefore 7,570 cu.yd. As the total number of bags of cement used for guniting was 53,718, the average mix was therefore about 1:3.8.

Confirming previous experience at Westcott Reservoir, it was found that sand containing 4 per cent moisture by weight was ideal for the best operation of the mixers and guns. This degree of wetness gave maximum production and uniform application of the gunite.

For this reason and for the reason that the mix was based on sand containing this moisture content, an effort was made to reduce the moisture content of the sand as received to this value before reaching the mixer. While it was not practicable to obtain this ideal at all times, the storing of sand in shallow piles and the manipulation that it received in transporting it from the storage pile to the mixers on a belt conveyor generally accomplished the desired result.

Determining cement ratio

The method used to determine the amount of cement in the dry mix and also in the gunite was to dehydrate a sample with a centrifuge and burning alcohol, and to sieve the material, obtaining the per cent of the sample by weight which passed a 200 sieve. By referring to a curve that was empirically established at the beginning of the job the amount of cement in the sample of mix was easily determined. Data for this curve (Fig. 4) were obtained by making up sample mixes of

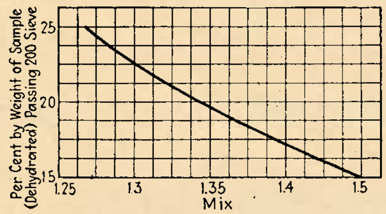


Fig. 4—Ratio of cement to sand in gunite of various proportions, with 4 per cent water content in the sand.

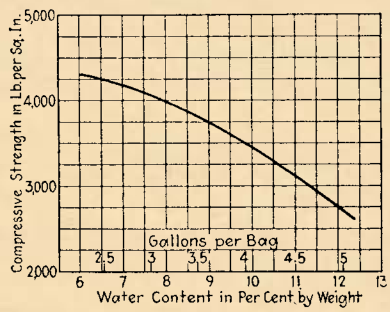


Fig. 5—Relation of strength to water content of gunite mixtures.

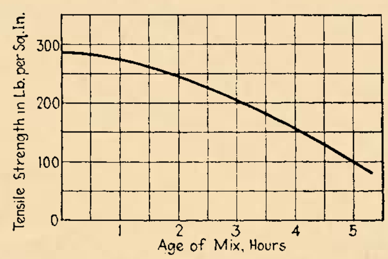


Fig. 6—Strength of gunite as affected by age of dry mix.

various ratios of cement to sand, the latter containing 4 per cent moisture by weight and sieving the samples. The amount passing the 200-sieve was directly proportional to the cement content. The per cent of the samples by weight passing the sieve are plotted as abscissae against mix ratios as ordinates.

Water content

The water content of the gunite was determined by dehydrating a sample of gunite with a centrifuge and alcohol. This was done as soon as it was shot, and the moisture content was expressed in terms of the total weight of the sample before dehydrating. To determine the water content to be used to obtain maximum strength and density, samples of gunite were shot at various moisture contents, and these samples were tested for compressive strength.

Fig. 5 plotted from data obtained by this test shows that the strength increases as the water content decreases. Water content is shown in per cent by weight of the sample and also in gallons per sack of cement. The latter values have been computed, the unit weight of the sand and cement used being known. A 10 per cent moisture content by weight is calculated to be a little over 4 gal. per sack. In the previous article (*ENR*, Nov. 19, 1931) the top of the strength curve corresponded to about 6 gal. per sack. This water content, however, was expressed in terms of the total amount of water used in shooting the gunite, including the moisture content of the sand and the water added at the nozzle. There is a loss of water in the rebound and a considerable loss in atomization. The latter has been found by test to be as high as 1 to 2 gal. per sack.

There was found to be a practical limit to the dryness at which the gunite could be shot. When shot with a moisture content of 8 per cent or less, it was difficult to incase properly the mesh in the gunite without entrapping rebound behind the wires. Experience showed that a 10 per cent moisture content was practical for the gunite under the mesh and 9 per cent for gunite above the mesh. This practice insured a good quality of gunite below the mesh and a denser harder layer above it.

At the beginning of the work, before the men were trained to this relatively dry shooting, gunite was shot somewhat wetter, probably averaging a moisture content of 11 per cent. At the completion of the job it was noted that the gunite that was shot with this moisture content had developed many more hair cracks than occurred in the gunite that was shot with less water. Moreover, the dryer gunite appeared to be of better quality, having a hard dense surface.

Gunite shot with a moisture content of 9 to 10 per cent is relatively dry. In shooting with this moisture content it is necessary to exercise great care to avoid rebound pockets and laminations. The question may be raised as to whether it is economically practicable to shoot with this low moisture content on account of the increase in rebound. If maximum density and strength is not required, it is doubtful if this degree of dryness is necessary. However, for reservoir linings, where the gunite is subjected to extreme ranges of temperature before and at the time of filling the reservoir, and where density and watertightness are of prime importance, experience at Woodland Reservoir would seem to justify the additional cost for sand and the labor of removing the rebound.

It does not follow that the most satisfactory water content on this work, expressed in per cent of a given sample of gunite, will be applicable on other work, as this ratio varies somewhat, depending on the characteristics of the sand and on the mix. It is comparatively easy to obtain these data for a given sand and mix. Once the most satisfactory water content is established on a job, uniform water content of the gunite can be maintained by frequent tests and careful observation.

Age of dry mix

During the early part of the work it was the custom to provide a storage of mixed material in the bin above the guns which would last from two to three hours in the event of a breakdown in the mixing plant. Some of the material in the bin that was mixed early in the morning might not be used until nearly noon, as it was the practice to empty the bin completely every four hours. Laboratory tests indicated that this mix produced gunite of poorer quality than did a fresh mix. Further to study this condition, mortar briquettes were made up at hour intervals after the initial dry-mixing of the ingredients, and the briquettes were tested for tensile strength. The briquettes showed a substantial loss of strength for every hour that elapsed after the mixing of the sand and cement (Fig. 6). From the time that these tests were made it was therefore the practice to provide storage of not over an hour's supply and to keep the mix in the bin above the guns thoroughly stirred up so that no dead areas occurred.

Another special test made was to run sand through a gun under normal operating conditions and to measure the percentage of this sand passing a 200-sieve. The amount of sand passing the sieve was found to be about 7 per cent greater than existed in the sand before shooting, showing that the gun has a considerable pulverizing effect on the soft particles of the sand. This emphasizes the need for a hard sand for gunite work, free from shale and other soft particles.

Strength

The unit strength of gunite, as shown on the accompanying curves, is the strength that was obtained for the particular tests which they illustrate and does not necessarily represent the strengths of gunite that can be obtained under favorable shooting conditions and with the best quality of materials.

The mix, of course, has a direct bearing on the strength. A series of seven-day specimens shot to study the effect of mix on strength showed a variation of from 4,000 lb. per sq.in. for a mix of 1:6 to more than 7,000 lb. per sq.in. for a mix of 1:3. Other specimens have been tested by the writer. These were made with a particularly hard sand and a mix of 1:3½, which tested from 7,000 lb. per sq.in. to nearly 10,000 lb. per sq.in. at an age of 6½ days.

Attention is called to Fig. 5, showing the relation of water content to compressive strength. The strengths obtained in this test were relatively low and do not truly represent the average strength obtained on the job. This is accounted for in part by the fact that the specimens were broken three days after they were made, whereas nearly all of the specimens broken in connection with the experimental work were seven days old. The relationship of water content to strength, however, is typical and agrees substantially, as far as this relationship is concerned, with the data developed on the Westcott Reservoir project.

Conclusions

The following conclusions may be drawn as a result of observations in reservoir-lining work at Syracuse.

Experience at Woodland Reservoir showed that to control the various phases of shooting gunite is not only desirable from an engineering point of view but is also practicable and an advantage to operation and production.

To measure and to regulate nozzle velocities insures a more uniform strength and density than could possibly be obtained by specifying a pressure under which the gun is to operate. The latter depends on many operating conditions and is not a measure of nozzle velocity. Nozzle-velocity meters provide a ready means of observing whether the flow of material through the hose is uniform, indicating at once any tendency to clog. The gunman may avert many shut-downs by slowing down the feed wheel until the obstruction has blown clear. This feature increases production. Then again, it appears that while insufficient velocity reduces the strength and density of the gunite, excessive velocity is also detrimental to the gunite in the same manner and increases the amount of rebound. Regulation can be readily controlled when the cement gun is equipped with a nozzle velocity meter.

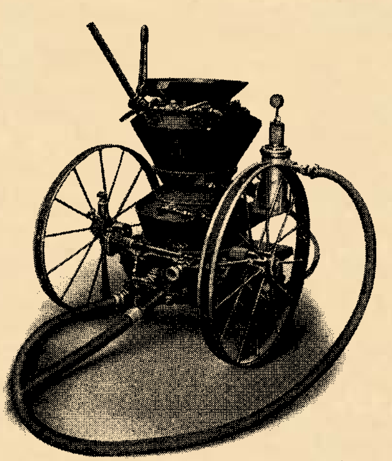
The value of the control of the water content in concrete work has been conclusively demonstrated in recent years. The experimental work to date would indicate that the same is true of gunite. Not only is strength and density sacrificed when excessive water is used, but the results at Woodland Reservoir showed that hair cracks at the surface of the gunite are much more prevalent when the gunite is shot relatively wet than when dry.

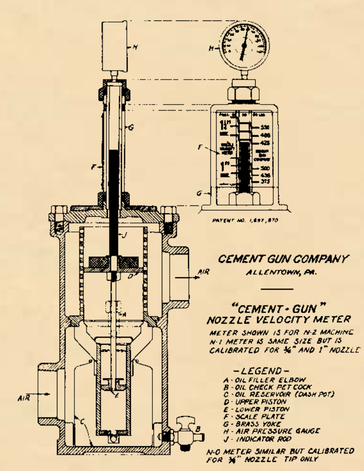
Controlling the moisture content of the sand at the mixer makes for smoothness of operation and maximum production. From 4 to 5 per cent moisture content by weight has given the best results on the work at Syracuse.

The sand should be well and uniformly graded. A hard sand is especially desirable for gunite work, as soft particles are pulverized, forming a dust that may form a film on the harder particles, thereby weakening the bonding action of the cement. The age of the mix is another factor to be considered in obtaining the best gunite. As soon as the cement comes in contact with the moist sand, hydration begins. The result is that the effectiveness of the cement is lost as the mix ages. The storage of mixed materials should therefore be kept at a minimum, and no inactive spots should be allowed to occur in storage bins.

The cement ratio in the mix should be kept constant for uniform gunite. With a change in moisture content in the sand, the per cent of bulking changes, requiring a modification of the mix to maintain a constant cement ratio. If continuous mixers are used, the method of feeding the hoppers should be uniform in order to maintain a constant ratio of cement to sand.

The importance of special care to secure good laps cannot be stressed too strongly, especially for watertight linings. Clean surfaces free from rebound are essential for a watertight bond.





Above, to the left, is a photo of the latest improved "CEMENT GUN." Attention is directed to the NOZZLE VELOCITY METER shown on the photo, (drawing on the right), which was developed from comparative tests made by Mr. Stewart at Westcott Reservoir, (described herein), and was first used on Woodland Reservoir. Since then, all new "CEMENT GUNS" have been equipped with the meter and meters may be purchased for attachment to all "CEMENT GUNS" previously sold. Write to CEMENT GUN COMPANY, Allentown, Pa., for prices and full particulars.

Blastcrete RMX-5000 Features Efficient, Rugged Design for Refractory and Shotcrete Applications

Blastcrete Equipment Company presents its RMX-5000 Mixer/Pump, a unit that boasts 15 percent more pumping pressure than any other machine of its size on the market.

The RMX-5000, one of five mixer/pumps in Blastcrete's lineup for refractory, shotcrete, and concrete repair, is user-friendly, safe, and rugged enough to handle demanding installations. The highly efficient mixer/pump is available with either a spiral mixer or a paddle mixer with a planetary gearbox. The spiral mixer is designed for conventional shotcrete in applications such as bridge repair projects. The paddle mixer provides the torque necessary for more demanding applications such as refractory, where materials are much more difficult to mix.

With its 2200 psi (15 MPa) piston pump, the RMX-5000 produces up to 5 yd^3 (4 m^3) per hour and can achieve vertical pumping distances up to 450 ft (137 m). An optional automatic lubrication system greases wear components hourly as necessary during operation. It also features a 1000 lb (454 kg) mixer capacity and a 1200 lb (544 kg) hopper capacity.

The RMX-5000 is available with a Kubota V3600 66-horsepower water-cooled diesel engine or a 50-horsepower electric motor. Blastcrete positions the engine safely away from the mixer and receiving hopper to prevent thermal transfer of heat to materials, which can accelerate setting. The placement of the engine also prevents airborne fiber from entering and clogging the air intake on the engine.

Blastcrete recommends thorough cleaning after each use to prevent material buildup and hardening, as well as possible damage to the unit. The RMX-5000 is designed for quick and simple cleanup with a hydraulic receiving hopper lift that provides easy access to the swing tube. The 3 x 18 in. (76 x 457 mm) swing tube is designed for fast cleaning and maintenance. An optional 2000 psi (14 MPa) hydraulic pressure washer can further ease cleanup.

The RMX-5000 is customizable for a range of applications and is available in trailer- or skid-mounted versions. The machine is CE Certified, meets European Union safety standards for equipment operation, and is backed worldwide by Blastcrete's unmatched customer service and support.

Blastcrete also offers free training seminars for customers at its Anniston, AL, location. In addition to teaching customers how to properly operate and maintain the machine, the company's experts demonstrate various installation and nozzling techniques.

Blastcrete Equipment Company has been manufacturing safe, reliable, and user-friendly solutions for the refractory and shotcrete industries for 63 years. With its complete product line of concrete mixers, pumps, and related products, Blastcrete is poised to meet the needs of commercial and residential construction, ICF and SCIP building systems, and refractory and underground markets. For more information, contact Blastcrete Equipment Company, 2000 Cobb Ave., Anniston, AL, 36202; call (800) 235-4867; fax (256) 236-9824; e-mail info@blastcrete.com; or visit **www.blastcrete.com**.

G.A. & F.C. Wagman, Inc., Expands Services to Include Shotcrete

G.A. & F.C. Wagman, Inc., announces the expansion of services to include shotcrete. Wagman has been continually expanding its geotechnical construction services over the past few years and now offers shotcrete, through a recent acquisition of specialized equipment and ACI certified nozzlemen for both wet- and dry-mixed shotcrete. Russ Ringler, an ACI Certified Nozzleman with over 40 years of experience with shotcrete/gunite, is Wagman's Shotcrete Manager.

This acquisition of certified shotcrete operators and equipment follows the recent announcement that Wagman acquired Key Construction Company, Inc., and its subsidiaries, D.W. Lyle Corporation and Key Constructors, Inc., each of whom provides heavy civil construction services out of offices in Virginia. The operation, formerly operating as Key Construction Company, Inc., and subsidiaries, now operates as D.W. Lyle—a Division of G.A. & F.C. Wagman, Inc.

Information about the benefits of shotcrete can be found on Wagman's website at **www.wagman.com/gafc/services/shotcrete.asp** or on ASA's website: **http://shotcrete.org/whyshotcrete**.

G.A. & F.C. Wagman, Inc., was founded in 1902 and continues on today as a fourth-generation, private family-owned general contracting business headquartered in York, PA. With offices in Pennsylvania and Virginia, G.A. & F.C. Wagman, Inc., is a heavy civil contractor and has grown to become a nationally recognized leader within the industry. Wagman's core competencies include design-build, bridges, marine construction, structures, highways, excavation, drainage, modified concrete, shotcrete, and geotechnical construction services. For more information about Wagman, please visit **www.wagman.com**.

Sika Acquires Leading Supplier of Structural Fibers for Shotcrete

Sika announces that it is acquiring Australian company Radmix Resources Pty Ltd and its manufacturing partner ASF (Australian Synthetic Fibres) Pty Ltd. Radmix is a leading supplier of structural fibers for shotcrete in Australia's mining industry. Last year, Radmix and ASF generated sales of CHF 8 million.

The acquisition of Radmix and ASF will allow Sika to expand its strong position in the mining sector. The structural fibers manufactured by Radmix are used for concrete reinforcement, shotcrete in particular.

For Sika, the mining industry represents a growing market that uses a large number of high-value Sika products, including shotcrete, specialty mortars, waterproofing systems, high-resistant coatings, and liquid membranes. The technological know-how brought by Radmix, in addition to Sika's comprehensive range, offers major potential for the development of new products and the expansion of an already-substantial offering for the mining industry.

As Sika integrates Radmix and ASF into the Sika Australia business, Radmix founder and present CEO Ray Desmond will help ensure a smooth transition into the new organization and assist in further promoting the development of structural fibers.

Quikrete Builds Home for Largest Saltwater Crocodile

The Toledo Zoo, Toledo, OH, recently welcomed the largest saltwater crocodile in North America to its animal family, which includes hundreds of mammals, amphibians, aquatic creatures, reptiles, insects and spiders, and birds. Transported from Australia, the 17 ft (5 m) crocodile required a spacious and ecologically friendly home at the Toledo Zoo, so A.A. Boos & Sons and Great Lakes Concrete Restoration turned to Quikrete®, a leading manufacturer of packaged cement mixes for the construction and home improvement markets, to help renovate an existing solarium into the ideal crocodile habitat.

Great Lakes Concrete Restoration applied more than 50 3000 lb (1361 kg) bulk bags of Quikrete Shotcrete MS over a reinforcing bar frame in the 80,000 gal. (302,833 L) solarium pool before Graphite Design sculpted the material into a landscape that reflected the crocodile's native Australian environment. The shotcrete surface was finished with a concrete stain to maximize the authenticity of this unique and highly anticipated zoo exhibit, which opened on May 24, 2013.

Quikrete Shotcrete MS is a single-component, microsilica-enhanced repair and restoration material that achieves a compressive strength of more than 9000 psi (62 MPa) at 28 days, and features very low rebound and permeability characteristics. Quikrete offers a full line of shotcrete products that can be applied through a wet or dry process to deliver a combination

of high strength, high adhesion, low rebound, and low sag. These characteristics make Quikrete Shotcrete MS ideal for use in rehabilitating bridges, tunnels, parking garages, ramps, piers, dams, and other concrete structures. Quikrete shotcrete has been used on many renovation and restoration projects, including the Pleasure Pier in Texas, Alcatraz Island and Stanford Linear Accelerator in California, and Spokane River in Washington.

For more information on Quikrete and its products and projects, visit **www.quikrete.com**; like it on Facebook; and follow it on Twitter @Quikrete.

Caltrans Announces Time, Money Savings on Monterey County Interchange Project

A recent change on the Highway 101/San Juan Road Interchange Project will save both money and time, Caltrans announced in a news release. The change replaces drystack stone retaining walls with sculpted shotcrete retaining walls along Highway 101 near San Juan Road.

Caltrans estimates that making this change will save close to $250,000 and reduce the construction time of the project by 2 months.

The $69 million San Juan Road Interchange Project will remove three major at-grade intersections (San Juan Road, Dunbarton Road, and Cole Road) and replace them with a new interchange near the Red Barn at San Juan Road and Highway 101. The project is supported by $10 million from the American Reinvestment and Recovery Act and $28 million from Proposition 1B, a 2006 voter-approved bond. In total, nearly $15 billion in Proposition 1B funds have been distributed statewide.

More than 60,000 vehicles travel daily through the Highway 101/San Juan Road area.

Granite Construction Company and MCM Construction, a joint venture, are contractors on the project, which is expected to be completed in the winter of 2014.

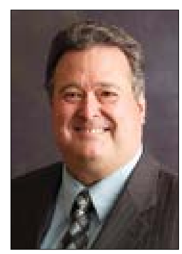
Industry Personnel

Kryton Welcomes New Inside Sales Coordinator


Alanna MacGillivray

Alanna MacGillivray joined the Kryton team in June 2013 as Inside Sales Coordinator. MacGillivray holds a Bachelor of Technology (Honors) from the British Columbia Institute of Technology, Burnaby, BC, Canada, and has previously worked in sales and marketing for the mining industry.

ICRI Welcomes New Technical Director


Ken Lozen

Kenneth M. Lozen, FACI, has joined the International Concrete Repair Institute (ICRI) as Technical Director. He has over 30 years of experience in restoration engineering, construction materials quality control, concrete technology and troubleshooting, project management, litigation, and structural rehabilitation. He was a Principal Engineer/Associate for NTH Consulting in Farmington Hills, MI, for many years. Lozen received his BS in civil engineering from the University of Detroit, Detroit, MI.

An ICRI Fellow, Lozen has served on the ICRI Technical Activities Committee and ICRI Committees 210, Evaluation, and 310, Surface Preparation. He has also served on many ACI Committees, including ACI Committee 228, Nondestructive Testing of Concrete; 546, Repair of Concrete; 563, Specifications for Repair of Structural Concrete in Buildings; and E706, Concrete Repair Education. During his career, Lozen has received several awards and has authored numerous articles on repair, restoration, strengthening, and maintenance of concrete structures.

ASA at World of Concrete 2014

Please see the Staff Editorial on page 6 for a detailed description of the many initiatives ASA has planned for the upcoming World of Concrete show. Please join us and help in communicating to the concrete industry the many benefits of the shotcrete process. Don't forget to register for **FREE** (some restrictions apply) using ASA's code: **A17**.

New ASA Compilations on Specifying and Quality & Evaluation

Two new compilations of articles from *Shotcrete* magazine are now available in ASA's bookstore:

Specifying Shotcrete—ASA Compilation #7: This 40-page black and white soft-cover book is a compilation of six previously published papers from ASA's *Shotcrete* magazine. Topics include shotcrete testing, the differences and similarities of shotcrete specifications, a guide specification for shotcrete structural walls, performance-based specifications for contracts, sustainability, and specifications for shotcrete rehabilitation projects.

Shotcrete: Quality & Evaluation—ASA Compilation #8: This 36-page black and white soft-cover book is a compilation of seven previously published papers on air content (as-shot versus as-batched), use of coarse aggregates, mixing water, freeze-thaw durability, curing, quality management, and an update of shotcrete standards. "Certification—Proper Use of an Important Tool," a valuable resource for understanding the role of certification in the effective and safe use of shotcrete, is also included.

Order your copy today at the ASA online store: **www.shotcrete.org/BookstoreNet**.

On-site Learning Seminars for Shotcrete

ASA offers FREE informational presentations to organizations with five or more architects, engineers, or specifiers in attendance.

The shotcrete process offers numerous quality, efficiency, and sustainability advantages, but proper knowledge of the process is critical to the creation of a quality specification and for the success of any specifier/owner employing the process. Maintaining a high level of quality for concrete placed via the shotcrete method is ASA's primary concern, and we have found this type of on-site presentation to be an excellent tool for all involved.

Presentations are often in a 60-minute format but can be tailored to any format you wish. A typical general presentation would include the following:

1. Introduction to shotcrete;
2. Advantages and benefits using the shotcrete process;
3. Dry- and wet-mix processes;
4. Specifications, material considerations, and typical performance guidelines;
5. Surface preparation;
6. Pre-construction, job-site conditions, and curing methods; and
7. Questions and answers.

ASA is also a registered AIA/CES Provider. Current ASA presentations offering AIA/LUs include:

- Shotcrete for repair and rehabilitation of concrete structures;
- Shotcrete for underground construction; and
- Introduction to shotcrete.

Contact ASA staff at info@shotcrete.org or (248) 848-3780 to arrange for an on-site informational presentation tailored to the needs of your group.

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 are working on a renovation of an existing shopping plaza where some of the existing walls are split face block. Would it be an acceptable application to resurface the block with shotcrete to achieve a smooth finish? If so, what is the thinnest we would be able to go?*

Answer: Shotcrete could be used for this application. The thickness of the overlay would be dependent on the material used. A potential concern would be the lines of the existing block showing on the new surface. We would suggest that you search for and review various ASA *Shotcrete* magazine articles (**www.shotcrete.org/pages/products-services/shotcrete-magazine.htm**) as well as ACI 506R-05, "Guide to Shotcrete" (available here: **www.shotcrete.org/BookstoreNet/default.aspx**).

Question: *We have a two-story shotcrete wall enclosing an indoor community pool. We are specifying a board-form finish for the interior and the exterior will have a parge finish coat. Are there any issues with the consistent moisture from the pool that should be addressed in the concrete mixture or topical sealant? How should we deal with the exterior versus interior finishes in regards to water intrusion protection and allowing the green concrete to "dry out" over time?*

Answer: Shotcrete is a method of placing concrete and the characteristics of shotcrete are those of cast concrete. Although the enclosed swimming pool will increase the interior humidity, the high humidity should have no detrimental effects on the exposed shotcrete, and may even be beneficial in reducing long-term drying shrinkage of the wall.

Both cast-in-place and shotcreted concrete are commonly used for construction of water tanks with constant exposure to water under significant hydraulic pressure. Using good construction techniques with good-quality concrete to build the tank's walls produces walls with no moisture evident on the exterior face of the tanks. Simply having a high-humidity atmosphere is a much less severe exposure and should not result in interior air moisture being transmitted into and through the shotcrete wall. Any coatings considered for aesthetics should follow the manufacturer's recommendations for drying time of concrete before application. If there is a concern about the permeability of the shotcrete wall, a premium shotcrete mixture including silica fume might prevent some issues on this application.

Question: *What difference would there be in the density of shotcrete before and after shooting? Is there any shotcrete mixture-design software in SI units available? Or any document of shotcrete mixture design in SI units for optimizing shotcrete design?*

Answer: Shotcrete is simply a placing method for concrete. Thus, the mixture design and material properties are the same as concrete. We are not aware of any software specific to shotcrete in any units. ACI 506R-05, "Guide to Shotcrete" (available here: **www.shotcrete.org/BookstoreNet/default.aspx**), has guidance on desirable mixture characteristics (aggregate grading, supplemental cementitious material [SCM], and so on) that would be helpful in developing a concrete mixture design for shotcrete placement.

Question: *I am a structural engineer working on underground structures such as tunnels and caverns. I would like to know the permissible shear strength of shotcrete to be taken for M30 Grade SFRS (M30 = 30 MPa [4350 psi] at 28 days). I would like to know more about its other properties, as well.*

Answer: Shotcrete is simply a placing method for concrete. Thus, the in-place material properties are essentially the same as cast concrete. A specific value for the shear is beyond the scope of our Association because many design and material properties can affect the shear capacity. We would suggest you engage a Professional Engineer who specializes in Underground Shotcrete. You should consult our Directory of Members to find such a consultant (**www.shotcrete.org/pages/products-services/Buyers-Guide/index.asp**). ACI 506R-05, "Guide to Shotcrete" (available here: **www.shotcrete.org/BookstoreNet/default.aspx**), would be a helpful primer to learn more about shotcrete.

Question: *I have a new construction project where I want to apply shotcrete to cast-in-place concrete columns and an elevated, post-tensioned concrete slab as a finish material. The finished application is intended to be in varying depths from 3 to 12 in. (76 to 305 mm) or more. The desired end result is a smooth, curvilinear, sculptural form. Is this type of application achievable?*

Answer: Shotcrete can and has been used to increase the size of columns and thicken overhead slabs while providing great-looking linear or curvilinear finishes. Examples of curvilinear finishes can be found in past *Shotcrete* magazine articles. You can search the *Shotcrete* magazine archives at **www.shotcrete.org/pages/products-services/shotcrete-magazine.htm**.

Question: *We just shot a wet-mix swimming pool for a customer. The shallow end depth starts at 39 in. (991 mm) to the top of the beam and over 10 ft (3 m) linear slopes down to 54 in. (1372 mm). From there we maintain our 1 to 3 ft (0.3 to 0.9 m) slope down to 8 ft (2 m) for the diving end of the pool.*

The customer would like to raise the entire shallow end pool floor up to the 39 in. (991 mm) depth. We prefer to use wet-mix shotcrete. The overlay would be tapered from the 39 in.

(991 mm) start to 15 in. (381 mm) thick at the 54 in. (1372 mm) depth. What would you recommend for this overlay to bond and not "pop loose" or cause crack transfer to pool plaster?

Answer: The proposed overlay will be similar to any repair where shotcrete is placed over existing concrete. Proper surface preparation is essential for allowing good bond. Guidance on surface preparation can be found in ACI 506R-05, "Guide to Shotcrete." It also appears you are suggesting tapering the thickness from 15 to 0 in. (381 to 0 mm). Feathering thickness down to 0 in. (0 mm) is not encouraged, and a minimum thickness should be established. Because the overlay section will be quite thick and experience differential shrinkage from the previously shot material, the overlay will require additional reinforcement to accommodate temperature and shrinkage stresses. You should consult with an engineer experienced in shotcrete design to establish the proper amount of reinforcement. The required reinforcement and cover over the reinforcement will control your minimum overlay thickness.

Question: *I am interested to know if any shotcrete contractors have shot a magnesium phosphate material (dry-process) before and, if so, could you detail the special requirements necessary in placing such a unique product?*

Answer: Phosphate-bonded refractory materials were routinely shot in cyclone boilers in the 1970s. These phosphate-bonded materials don't have a cement bond, but achieve a chemical bond when heat is applied. Without knowing the precise formulation of the mixture and grain sizes involved, we cannot tell you definitively that your specific material can be shotcreted. However, there is a long history of successful past experience with phosphate-bonded refractory materials being shot with the dry-mix process. You may want to consider a field trial before construction to verify your specific mixture works with your dry-mix shotcrete equipment.

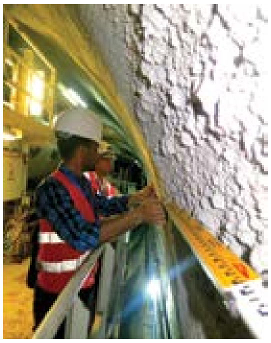
Question: *I am an engineer working on a project involving shotcrete and earthwork. The shotcrete that was placed has some expansion cracks, which we expected. I would like to know the best way to repair them. Is there some type of waterproof coating/grout that can be applied between the cracks? Part of the cracks will be continuously under water. The shotcrete is the surfacing material for a diversion ditch at a mine, and we need to recommend some remediation solutions to our client.*

Answer: There are many products in the marketplace for repairing cracks. Because shotcrete is simply a method for placing concrete, any method for concrete crack repair would be applicable. It would be wise to use a product that filled the cracks and is able to tolerate thermal movement in the future (not a brittle product). Many injectable polyurethane grouts can accomplish this. Surface-applied coatings would need an adequate thickness and elasticity to tolerate moving cracks. We suggest that you contact one of our corporate members who is familiar with your area and get their specific advice. Visit **www.shotcrete.org/pages/products-services/Buyers-Guide/index.asp**.

Question: *How might one add fibers to a gunite (dry-mix) application? I have heard of some companies adding them by hand at the base of the auger and others who poured them over their sand and mixed them in with a loader before loading it into the truck. Is there a more efficient way to add them to a dry mixture so that they are distributed evenly throughout?*

Answer: Many of our members add them by hand at the mixer and have had good success when using an adequate mix time. Another method is to have the mix blended at a bag mix plant with the fibers.

Question: *We have a 17 mile (28 km) long TBM tunnel for water that will drive our underground powerhouse. Is there a recommended shotcrete surface texture we could use? Our contractor is using 0.31 in. (8 mm) aggregate, but they are getting an undulating surface. Can you provide some clarity as to what we should ask our contractor to try and achieve?*



Answer: Shotcrete can be applied with many different textures. The nozzle finish shown is very rough, even for a natural gun finish. Nozzle finishes can be done smoother than this. Another technique would be to use a broom to make it smoother after it is shot. Other finishes include wood float, rubber or sponge float, broom, and smooth trowel finishes. There are many examples of finishes shown in articles in *Shotcrete* magazine (**www.shotcrete.org/pages/archive-search/Archive-Search.asp?query=finishes&srchtype=ALL**).

Question: *I am an engineering technologist working on a landslide project where shotcrete had been applied to stabilize the sandstone head scarp at the crest of the slope. The shotcrete was applied in 1998. After a recent inspection, it was noted that the surface of the shotcrete had some cracking in some sections. How can this be repaired? Can the cracks simply be filled with a grout/mortar mixture of some sort or do the cracked sections have to be removed entirely and shotcrete be reapplied?*

Answer: Shotcrete can and has been used to overlay previously installed shotcrete or concrete that has cracked over time. It would be advisable that you engage an engineer knowledgeable in geotechnical engineering and concrete properties to formalize a solution. It is important that the cause of the cracks be determined and adequate reinforcing be designed to ensure that the cracks do not propagate through the overlaid shotcrete.

Question: *I am a structural engineer and I am supposed to design structures for shotcrete applications. Should I calculate and check its stability by the "working stress method?" Or, could I use the "ultimate limit design?" Are there regulations or specifications about the application of method on ACI? Finally, is elastic coefficient different between normal concrete and shotcrete?*

Answer: Shotcrete is a method for placing concrete. Thus, the concrete placed by the shotcrete method has the same physical properties as cast concrete with the same mixture proportions. Either working stress or ultimate strength methods used for concrete design are applicable. Local building codes may require a particular design approach.

Question: *I have a customer who would like to place 2 in. (51 mm) of shotcrete onto our geotextile canal liner, which has been used for many years with 2 to 4 in. (51 to 102 mm) of shotcrete. In all of these previous projects, contraction joints were installed. For this project, the customer is asking whether this is an absolute requirement, as the geocomposite canal liner beneath is the water containment component. Does it make a difference in terms of cracking and joints whether the shotcrete is 2 or 4 in. (51 or 102 mm) thick? What is the typical finishing that is done on canal projects?*

Answer: Long expanses of concrete canal lining exposed to the sun and weather would experience significant internal tensile drying shrinkage stresses. Regular contraction joints help to relieve the internal tension created by concrete shrinkage. If no contraction joints are provided, shrinkage will still occur and the concrete lining will produce its own contraction joints, better known as "cracks." Unfortunately, the resulting cracking will be random and can vary significantly in size and length. Thus, contraction joints are a good approach to help induce cracking at regular, controlled locations. If the client doesn't want contraction joints, they need to understand that cracking will be much more extensive and likely more noticeable.

Theoretically, with the same percentage of embedded reinforcement, cracking between a 2 or 4 in. (51 or 102 mm) should not be substantially different. Of course, the 4 in. (102 mm) thick shotcrete section would require twice the concrete material and twice the embedded reinforcement to maintain the same percentage of reinforcement. A 2 in. (51 mm) thick section could have some difficulty in maintaining adequate cover over embedded reinforcing bars. The designers could also consider using fiber-reinforced shotcrete to help control shrinkage and temperature stresses, although fairly high dosages are needed for effective elimination of reinforcing bars. More guidance on fiber-reinforced shotcrete is available in ACI 506.1R-08, "Guide to Fiber-Reinforced Shotcrete" (**www.shotcrete.org/BookstoreNet/ProductDetail.aspx?itemid=506108**). A 2 in. (51 mm) overlay is absolutely the least possible and 3 or 4 in. (76 or 102 mm) is far more normal in practice.

Canals are generally specified to have a natural gun finish, a rough broom finish, or a light broom finish.

Question: *I have been asked to come up with a 5000 psi (35 MPa) in 24 hours shotcrete mixture, using cement, fly ash, silica fume, and fine aggregate. I need some advice on a mixture.*

Answer: Design of a concrete mixture to be placed by the wet-mix shotcrete method is essentially the same as normal cast-in-place concrete mix design. The major differences with shotcrete mixtures are:

- The maximum coarse aggregate size is generally limited to about 3/8 in. (9.5 mm);
- They use a fairly low water-cementitious material ratio (*w/cm*) and slump to allow shooting on vertical surfaces without sloughing;
- The potential to use an accelerator that can be added at the nozzle; and
- The pumpability is an important workability characteristic.

Since you desire a high-early-strength mixture, using fly ash as a supplemental cementitious material (SCM) wouldn't be recommended because it slows set and strength gain at early ages. Microsilica may be beneficial for early strength gain. Consideration should be given to using accelerator added at the nozzle. There is some guidance on concrete mixture design in ACI 506R-05, "Guide to Shotcrete" (**www.shotcrete.org/BookstoreNet/ProductDetail.aspx?itemid=506R-05**); however, because local materials (aggregates, cements, SCMs) can vary significantly, you should consult with an engineer or concrete testing laboratory familiar with shotcrete to produce and test a mixture design to meet your requirements.

Question: *Can shotcrete be used to help seal a leaking pond? We have a 1.5 acre (6070 m²) pond that we are in the process of completing. We spread 90,000 lb (40,823 kg) of bentonite in, but the bentonite washed off the steep banks and now we are stuck with a half-full pond. Would shotcrete be a practical solution for our problem?*

Answer: Properly designed shotcrete (both concrete materials and reinforcing are important in the design) placed by an experienced shotcrete contractor can certainly be used to provide a somewhat watertight lining for your pond that will be serviceable, durable, and require little to no maintenance for decades to come. We would suggest you consult with an engineer or shotcrete contractor experienced in this type of shotcrete work. You may use our online Buyer's Guide (**http://shotcrete.org/pages/products-services/Buyers-Guide/index.asp**) to find an ASA corporate member consultant or contractor to assist you.

Shotcrete Calendar

NOVEMBER 9-14, 2013
2013 International Pool | Spa | Patio Expo
Theme: "Building Beyond the Borders"
Register using ASA's source code: BN05 for FREE Expo-only and 15% off Conference Packages
Mandalay Bay Convention Center
Las Vegas, NV
www.poolspapatio.com

NOVEMBER 12-13, 2013
ASA's Nozzleman Education Class
in conjunction with the 2013 International Pool | Spa | Patio Expo
Tuesday November 12: 3 pm to 6 pm;
Wednesday November 13: 8 am to 12 noon
Mandalay Bay Convention Center
Las Vegas, NV
www.poolspapatio.com

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

NOVEMBER 13-15, 2013
ICRI 2013 Fall Convention
Theme: "Looking Back— ICRI Celebrates Its 25th Anniversary"
Fairmont Chicago, Millennium Park
Chicago, IL
www.icri.org

DECEMBER 8-11, 2013
ASTM International Committee C09, Concrete and Concrete Aggregates
Hyatt Regency Jacksonville Riverfront
Jacksonville, FL
www.astm.org

JANUARY 20-24, 2014
2014 World of Concrete
Theme: "Your Success Is Our Legacy"
Exhibits: January 21-24
Seminars: January 20-24
Visit ASA's Booth #S10839 (New location!)
Register using ASA's source code: **A17** for **FREE** exhibit-only Registration (restrictions apply)
Las Vegas Convention Center
Las Vegas, NV
www.worldofconcrete.com

JANUARY 20, 2014
ASA WOC 2014 Committee Meetings
Las Vegas Convention Center
Las Vegas, NV
www.shotcrete.org

JANUARY 21, 2014
ASA Shotcrete Nozzleman Education Class
in conjunction with WOC 2014
Speakers: Oscar Duckworth and Charles Hanskat
9:00 am to 4:00 pm
WOC Registration code: **ASATU**
Las Vegas Convention Center
Las Vegas, NV
www.worldofconcrete.com

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

JANUARY 21, 2014
ASA Annual Outstanding Shotcrete Project Awards Banquet
6:00 pm to 7:30 pm: Registration, networking, cocktails, and hors d'oeuvres
7:30 pm to 11:00 pm: Plated dinner and awards ceremony
Further networking and cash bar available after the awards ceremony
New York, New York Las Vegas Hotel & Casino
Staten Island Ballroom
Las Vegas, NV
www.shotcrete.org

JANUARY 22, 2014
ASA Shotcrete Seminar: Shotcrete for Infrastructure and Building Repair, Rehabilitation, and Repurposing
in conjunction with WOC 2014
Speakers: Charles Hanskat and Marcus von der Hofen
1:30 pm to 3:00 pm
WOC Registration code: **WE139**
Las Vegas Convention Center
Las Vegas, NV
www.worldofconcrete.com

FEBRUARY 23-26, 2014
2014 SME Annual Meeting & Exhibit
Theme: "Leadership in Uncertain Times"
Salt Palace Convention Center
Salt Lake City, UT
www.smenet.org/meetings

Shotcrete Calendar

MARCH 22, 2014
ASA Spring 2014 Committee Meetings
Grand Sierra Resort
Reno, NV
www.shotcrete.org

MARCH 23-27, 2014
ACI Spring 2013 Convention
Theme: "Concrete Endures"
Grand Sierra Resort
Reno, NV
www.concrete.org

JUNE 22-25, 2014
ASTM International Committee C09, Concrete and Concrete Aggregates
Sheraton Toronto
Toronto, ON, Canada
www.astm.org

OCTOBER 25, 2014
ASA Fall 2014 Committee Meetings
Hilton Washington
Washington, DC
www.shotcrete.org

OCTOBER 26-30, 2014
ACI 2014 Fall Convention
Hilton Washington
Washington, DC
www.concrete.org

DECEMBER 7-10, 2014
ASTM International Committee C09, Concrete and Concrete Aggregates
Sheraton New Orleans
New Orleans, LA
www.astm.org

AMERICAN SHOTCRETE ASSOCIATION 2013 Buyers Guide

The following list of ASA Corporate Members is current as of October 7, 2013. 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/Address	Contact information	Specialties: Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Acme America Inc. PO Box 269 Coopersburg, PA 18036-0269	Website: http://www.acmeamerica.com/ Contact: John Ferraris Phone: 800-458-2263 E-mail: acme@acmeamerica.com					•		
Active Minerals International, LLC 34 Loveton Circle Sparks, MD 21152	Website: http://www.activeminerals.com Contact: Joey Bell Phone: 571-377-9158 E-mail: r.bell@activeminerals.com	•						
Advanced Shotcrete Inc. 887 N 100 E, Ste 4 Lehi, UT 84043	Website: http://www.advancedshoring.com Contact: Per-Ole Danfors Phone: 801-908-7664 E-mail: pdanfors@advancedshoring.com				•			
Aircrete Systems LP Inc. 4 Industry Way SE Calgary, AB T3S 0A2, Canada	Website: http://aircretesystems.com/ Contact: Jack Radu Phone: 403-203-0492 E-mail: lamanagement@shaw.ca			•	•			
Airplaco Equipment Company 4141 Airport Rd Cincinnati, OH 45226-1643	Website: http://www.airplaco.com/ Contact: Tom Norman Phone: 513-321-4511 E-mail: sales@airplaco.com					•		
AMEC Environment & Infrastructure 4445 Lougheed Hwy, Ste 600 Burnaby, BC V5C 0E4, Canada	Website: http://www.amec.com/ Contact: John Laxdal, PE Phone: 604-294-3811 E-mail: john.laxdal@amec.com			•				
American Concrete Restorations Inc. 11S375 Jeans Rd Lemont, IL 60439-8839	Website: http://www.americanconcreterestorations.com Contact: Cathy Burkert Phone: 630-887-0670 E-mail: cathy@americanconcreterestorations.com				•			
American Shotcrete Construction 3951 E Palm St Mesa, AZ 85215-1116	Website: http://www.americanshotcreteconstrucionaz.com Contact: Robert Porter Phone: 480-833-8068 E-mail: bfish519@aol.com	•		•	•			
American Standard Conc Pumping Hawaii Inc. 94-400 Koaki St Waipahu, HI 96797-2874	Website: http://www.ascphi.com Contact: Gregory L. Perrin Phone: 808-479-7867 E-mail: gperrin@ascphi.com			•	•	•		
Apex Testing Laboratories, Inc. 3450 3rd St, Ste 3E San Francisco, CA 94124	Website: http://www.apextestinglabs.com Contact: Abdel-Kader Khelifa Phone: 415-550-9800 E-mail: abdel@apextestinglabs.com			•				
Arco Gunite, Inc. 1448 N Glassell St Orange, CA 92867-3612	Contact: Tammy Counoupas Phone: 714-771-6022 E-mail: arcoguniteinc1976@yahoo.com				•			

Name/Address	Contact information	Specialties						
		Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
ATEK Fine Chemical Co. Ltd. 704 Sangdang-ri, Wonnam-myeon, Eumseong-gun Chungcheongbuk-do, NS 369-963, Korea	Website: http://www.atekfc.com Contact: Mi-Jung Kim Phone: 011-82432661985 E-mail: hslee@atekfc.com	•						
Atlantic Underground Services Ltd. 425 Pine Glen Rd Riverview, NB E1B 4J8, Canada	Website: http://www.ausltd.com/ Contact: Terry Keiver Phone: 506-387-8160 E-mail: info@ausltd.com				•			
Azteca Gunite 6626 Flintlock Rd Houston, TX 77040-4319	Website: http://www.aztecagunite.com/ Contact: Ozzie Martinez Phone: 713-462-5566 E-mail: info@aztecagunite.com				•			
BASF Admixtures Inc. 23700 Chagrin Blvd Cleveland, OH 44122-5506	Website: http://www.basf-admixtures.com/ Contact: Jeannine Jones Phone: 216-839-7227 E-mail: jeannine.jones@basf.com	•						
Bekaert Corporation 1395 S Marietta Pkwy SE, Bldg 500, Ste 100 Marietta, GA 30067-4440	Website: http://www.bekaert.com Contact: Heidi Helmink Phone: 404-433-6823 E-mail: heidi.helmink@bekaert.com			•			•	
BelPacific Excavating & Shoring Ltd. 3183 Norland Ave Burnaby, BC V5B 3A9, Canada	Website: http://www.belpacific.com Contact: Gregory Samcheck Phone: 604-205-0002 E-mail: greg@belpacific.com			•	•			
The Blanchard Group 2380 Route 315 Dunlop, NB E8K 2J6, Canada	Website: http://www.blanchardgroup.ca Contact: Rene Blanchard Phone: 506-725-2132 E-mail: rene@blanchardgroup.ca							•
Blastcrete Equipment Company PO Box 1964 Anniston, AL 36202-1964	Website: http://www.blastcrete.com/ Contact: Jim Farrell Phone: 256-235-2700 E-mail: jim@blastcrete.com			•		•		
Boulderscape Inc. 33081 Calle Perfecto, Ste A San Juan Capistrano, CA 92675-4762	Website: http://www.boulderscape.com Contact: Mark Allen Phone: 949-661-5087 E-mail: steve@boulderscape.com				•			
Buesing Corp. 3045 S 7th St Phoenix, AZ 85040-1170	Website: http://www.buesingcorp.com Contact: Kevin Somerville Phone: 602-233-3339 E-mail: ksomerville@buesingcorp.com			•	•			
BVR Construction Company Inc. 8 King Road Churchville, NY 14428	Contact: Chip Stephenson Phone: 585-458-9750 E-mail: cstephenson@bvrconstruction.com				•			•
California Skateparks 273 N Benson Ave Upland, CA 91786-5614	Website: http://www.californiaskateparks.com Contact: Joseph M. Ciaqlia Jr. Phone: 909-949-1601 E-mail: info@californiaskateparks.com			•	•			
CCS Group LLC 655 South St, Suite #2 Seward, NE 68434-2439	Website: http://www.ccsgrouponline.com Contact: Cheyenne Wohlford Phone: 855-752-5047 E-mail: cheyenne@ccsgrouponline.com			•	•		•	•
Clark Foundations, LLC 7500 Old Georgetown Rd Bethesda, MD 20814-6133	Website: http://www.clarkconstruction.com Contact: Irvin Ragsdale Phone: 301-272-8110				•			

www.Shotcrete.org/BuyersGuide

Name/Address	Contact information	Specialties: Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Classic Tile & Plaster, LLC 746 Gary Dr Byram, MS 39272	Contact: Jorge De Ochoa Jr. Phone: 601-372-0164 E-mail: jd8a@icloud.com		•	•	•		•	•
Coastal Gunite Construction Company PO Box 977 Cambridge, MD 21613-0977	Website: http://www.coastalgunite.com Contact: R. Curtis White Jr. Phone: 410-228-8100 E-mail: curt@coastalgunite.com				•			
Concrete Strategies 2199 Innerbelt Business Center Dr Saint Louis, MO 63114-5721	Website: http://www.concretestrategies.com/ Contact: Curt Costello Phone: 314-581-0901 x9 E-mail: costelloc@concretestrategies.com			•	•			
Construction Forms, Inc. PO Box 308 Port Washington, WI 53074-0308	Website: http://www.conforms.com Contact: Jim Bodeker Phone: 800-223-3676 E-mail: jim.bodeker@conforms.com					•		
Contech Services, Inc. PO Box 84886 Seattle, WA 98124-6186	Website: http://www.contechservices.com Contact: Peter Barlow Phone: 206-763-9877 E-mail: pete@contechserviceswa.com				•			
Cowin & Company Inc. PO Box 19009 Birmingham, AL 35219-9009	Website: http://www.cowin-co.com Contact: John J. Cowin Jr. Phone: 205-945-1300 E-mail: jcowinjr@cowin-co.com				•			
The Crom Corporation 250 SW 36th Ter Gainesville, FL 32607-2863	Website: http://www.cromcorp.com Contact: Lars Balck Jr., PE Phone: 828-277-2666 E-mail: 4lob@cromcorp.com				•			
Cruz Concrete & Guniting Repair Inc. 1405 Winesap Dr Manasquan, NJ 08736-4020	Contact: Warren C. Cruz Phone: 732-223-2206 E-mail: cruzconcrete@gmail.com				•			
C-TEC, Inc. 1928 S Lincoln Ave, Suite 100 York, NE 68467-9467	Website: http://www.ctecconcrete.com Contact: Greg Wurst Phone: 402-362-5951 E-mail: ctec@ctecconcrete.com				•			
CTS Cement Manufacturing Corporation 11065 Knott Ave, Suite A Cypress, CA 90630-5149	Website: http://www.ctscement.com Contact: Mike Ballou Phone: 801-209-0599 E-mail: mballou@ctscement.com	•	•					•
Custom Crete Inc. 4433 Terry O Ln Austin, TX 78745-2039	Website: http://www.custom-crete.com Contact: Bill Heath Phone: 512-443-5787 E-mail: bill.heath@oldcastle.com				•	•		•
Davies Geotechnical Inc. #2-1 1520 Cliveden Ave Delta, BC V3M 6J8, Canada	Website: http://www.daviesgeotechnical.com Contact: Paul Davies Phone: 604-395-2300 E-mail: pauldavies@daviesgeotechnical.com			•				
DBM Contractors, Inc. PO Box 6139 Federal Way, WA 98063	Website: http://dbmcm.com Contact: Sue Wolf Phone: 253-838-1402 E-mail: suew@dbmcm.com				•			
Dees Hennessey Inc. 200 Industrial Rd San Carlos, CA 94070-6257	Website: http://www.deeshenn.com/ Contact: Daniel M. Evans Phone: 650-595-8933 E-mail: dhi@dees-hennessey.com				•			

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Name/Address	Contact information	Specialties: Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Delta Gunite Solano Inc. 1735 Enterprise Dr, Suite #103 Fairfield, CA 94533-6822	Website: http://www.deltagunitesolano.com Contact: Philip Kassis Phone: 707-425-7293 E-mail: deltasolano@sbcglobal.net				•			•
Delta Industrial Services Inc. PO Box 1109 Delta Junction, AK 99737-1109	Website: http://www.deltaindustrial.com Contact: Mike Crouch Phone: 907-895-5053 E-mail: mike@deltaindustrial.com							•
Deluxe Shotcrete & Concrete Construction PO Box 385 Santa Rosa, CA 95402-0385	Website: http://www.deluxeshotcrete.com Contact: Kristen Humphreys Phone: 707-568-1200 E-mail: kristen@deluxeshotcrete.com			•	•			•
DN Tanks 11 Teal Road Wakefield, MA 01880	Contact: Rachelle Graham Phone: 781-224-5102 E-mail: rachelle.graham@dntanks.com				•			
Dome Technology 3007 E 49th N Idaho Falls, ID 83401-1337	Website: http://www.dometech.com Contact: Bryan Butikofer Phone: 208-529-0833 E-mail: butikofer@dometech.com				•			
DOMTEC International LLC 4355 N Haroldsen Dr Idaho Falls, ID 83401-1105	Website: http://www.domtec.com Contact: Ryan Poole Phone: 208-522-5520 E-mail: domtec@domtec.com			•	•			
Donald J Scheffler Construction 15815 Amar Rd City Of Industry, CA 91744-2107	Website: http://www.donaldschefflerconstruction.com Contact: Donald J. Scheffler Phone: 626-333-6317 E-mail: mailbox@donaldjscheffler.com				•			
Drake Inc. 1919 Road Q Waco, NE 68460-8826	Website: http://www.drakeinc.net Contact: David Drake Phone: 402-362-1863 E-mail: davedrake@windstream.net				•			
Drakeley Industries LLC 74 Hickory Ln Bethlehem, CT 06751-2308	Website: http://www.drakeleypools.com Contact: William T. Drakeley Jr. Phone: 203-263-7919 E-mail: bill@drakeleypools.com			•	•			
Drill Tech Drilling & Shoring, Inc. 2200 Wymore Way Antioch, CA 94509-8548	Website: http://www.drilltechdrilling.com Contact: Ryan Nagle Phone: 925-978-2060 E-mail: ryan@drilltechdrilling.com			•	•			
Eastco Shotcrete, LLC 1211 Kennedy Blvd Manville, NJ 08835	Website: http://www.eastcoastshotcrete.com Contact: Tommy Pirkle Phone: 908-526-2777 E-mail: tommy@eastcoastshotcrete.com				•			
Eastern Gunite Company Inc. PO Box 557 Exton, PA 19341-0557	Website: http://www.easterngunite.com Contact: Thomas F. Lyons Phone: 610-524-5590 E-mail: egunite@easterngunite.com				•			
Elkin Hi Tech Inc. 2879 Oakland Ave Indiana, PA 15701-3293	Website: http://www.elkinhitech.com Contact: Frank Holuta Phone: 724-349-6300 E-mail: elkin@elkinhitech.com					•		
Engineering & Construction Innovations Inc. 7012 6th St N Oakdale, MN 55128-6146	Website: http://www.eandcinnovations.com/ Contact: Shane McFadden Phone: 651-298-9111 E-mail: shane@eandci.co				•			

www.Shotcrete.org/BuyersGuide

Name/Address	Contact information	Specialties: Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Epoxy Design Systems Inc. PO Box 19485 Houston, TX 77224-9485	Website: http://www.epoxydesign.com Contact: Hank Taylor Phone: 713-461-8733 E-mail: hank@epoxydesign.com			•	•			
ESD Inc. PO Box 6104 Farmington, NM 87499-6104	Contact: Matthew Mordecki Phone: 505-320-6612 E-mail: matt@esdnm.com				•			
Facca Incorporated 2097 County Rd 31 RR 1 Ruscom Station, ON N0R 1R0, Canada	Website: http://www.facca.com Contact: Don Gardonio Phone: 519-975-0377 E-mail: don@facca.com				•			
Fenton Rigging & Contracting Inc. Fenton Gunite Shotcrete Division 225 Stone Mill Rd Jacksboro, TN 37757-4000	Website: http://www.fentonrigging.com Contact: Michael Milton Phone: 423-566-9909 E-mail: mmiltonhb@aol.com			•	•			•
Fibercon International Inc. 100 S 3rd St Evans City, PA 16033-9264	Website: http://www.fiberconfiber.com Contact: Nicholas Mitchell Jr. Phone: 724-538-5006 E-mail: nick@fiberconfiber.com				•		•	
Forta Corporation 100 Forta Dr Grove City, PA 16127-6308	Website: http://www.fortacorp.com Contact: Daniel T. Biddle Phone: 800-245-0306 E-mail: info@fortacorp.com						•	
Frontier-Kemper Constructors Inc. 1695 Allen Rd Evansville, IN 47710-3394	Website: http://www.frontierkemper.com Contact: Jim McMahon Phone: 812-426-2741 E-mail: jmcmahon@frontierkemper.com				•			
GA & FC Wagman, Inc. 3290 N Susquehanna Trl York, PA 17406	Website: http://www.wagman.com Contact: Russ Ringler Phone: 540-955-4034 E-mail: rhringler@wagman.com				•			
Gary Carlson Equipment Co. 10720 Mankato St NE Blaine, MN 55449	Website: http://www.garycarlsonequip.com Contact: Gary R. Carlson Phone: 763-792-9123 E-mail: gary@garycarlsonequip.com					•		
Genesis 3, Inc. 110 Blossoms Ct Murfreesboro, TN 37129-3252	Website: http://www.genesis3.com Contact: Brian Van Bower Phone: 615-907-1274 E-mail: lisa@genesis3.com			•	•			
Georgia Gunite and Pool Company 828 Victoria Place Woodstock, GA 30189	Contact: Tina Davis Phone: 770-926-5150 E-mail: tina@georgiagunite.com				•			
Getman Corporation 59750 34th Ave Bangor, MI 49013-1259	Website: http://www.getman.com Contact: Gene L. Lomboy Phone: 269-427-5611 E-mail: glomboy@getman.com					•		
Gib-San Pools Ltd. 59 Milvan Dr Toronto, ON M9L 1Y8, Canada	Website: http://www.gibsanpools.com Contact: Edward D. Gibbs Phone: 416-749-4361 E-mail: ed@gsplc.ca			•	•			
Group Works LLC PO Box 7269 Wilton, CT 06897-7269	Website: http://www.groupworksllc.com Contact: James Scott Phone: 203-834-7905 E-mail: jamie@groupworksllc.com			•	•			

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Name/Address	Contact information	Specialties: Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Gunite Specialists Inc. 152 Mathers Rd Ambler, PA 19002-4100	Website: http://www.gunitespecialists.com Contact: David Reeves Phone: 610-239-0988 E-mail: info@gsipoolfinishes.com				•			
Gunite Supply & Equipment Co. 1726 S Magnolia Ave Monrovia, CA 91016-4511	Website: http://www.gunitesupply.com Contact: Chris Marston Phone: 888-393-8635 E-mail: casales@gunitesupply.com					•		
H&H Restoration PO Box 11 Aurora, NE 68818-0011	Contact: Harold Hudiburgh Phone: 402-631-7649 E-mail: hh_resto@yahoo.com			•	•			
Haggerty Pools PO Box 4657 Stamford, CT 06907	Website: http://www.haggertypools.com Contact: Roger Haggerty Phone: 203-348-6899 E-mail: rhaggerty@haggertypools.com			•	•	•		
Hayward Baker Inc.—Craig Olden Division PO Box 5000 Little Elm, TX 75068-9000	Website: http://www.oldeninc.com Contact: Trevor Bray Phone: 972-294-5000 E-mail: tbray@haywardbaker.com			•	•			
HC Matcon Inc. Unit 4, 122 Earl Thompson Road Ayr, ON N0B 1E0, Canada	Website: http://www.hcgroup.ca Contact: Martin Halliwell Phone: 519-623-6454 E-mail: martinh@hcgroup.ca				•			
Hydro Arch 900 W Warm Springs Rd, Ste 106 Henderson, NV 89011	Website: http://www.hydro-arch.com Contact: Wolf Michelson Phone: 702-566-1700 E-mail: wmichelson@hydro-arch.com				•			
J Tortorella Swimming Pools Inc. 1764 County Road 39 Southampton, NY 11968-5204	Website: http://www.tortorella.com Contact: Joe Tortorella Phone: 631-728-1380 E-mail: info@tortorella.com	•		•	•			•
JE Tomes & Associates 2513 140th Pl Blue Island, IL 60406-3588	Website: http://www.jetomes.com Contact: Joseph E. Tomes Phone: 708-653-5100 E-mail: joe@jetomes.com	•	•					•
John Rohrer Contracting Company Inc. 2820 Roe Ln Kansas City, KS 66103-1543	Website: http://www.johnrohrercontracting.com Contact: Brandon D. McMullen Phone: 913-236-5005 E-mail: brandon@johnrohrercontracting.com				•			
Joseph B Fay Company 100 Sky Lane Tarentum, PA 15084	Contact: Ann Michalski Phone: 724-265-4600 E-mail: amichalski@jbfayco.com				•			
K & G Concrete Inc. 2564 La Croix Dr Roseville, CA 95661	Website: http://kgconcretepumping.com Contact: Herman Keaven Guillory Phone: 916-539-6652 E-mail: keaven@kgconcretepumping.com	•	•	•	•	•	•	•
KHM Inc. PO Box 2672 Binghamton, NY 13902-2672	Contact: Kathleen Hall Phone: 607-773-0076 E-mail: khmwbe1989@stny.rr.com							
King Packaged Materials Company 3385 Harvester Rd, P.O. Box 699 Burlington, ON L7R 3Y5, Canada	Website: http://www.kingshotcrete.com Contact: Joe Hutter Phone: 905-639-2993 E-mail: jhutter@kpmindustries.com					•	•	•

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Name/Address	Contact information	Specialties: Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Knowles Industrial Services Corp. 295 New Portland Rd Gorham, ME 04038-1867	Website: http://www.knowlesindustrial.com Contact: Dan Maloney Phone: 207-854-1900 E-mail: dmaloney@knowlesindustrial.com				•			
Kryton International Inc. 1645 Kent Ave North E Vancouver, BC V5P 2S8, Canada	Website: http://www.kryton.com Contact: Jillian Work Phone: 604-324-8280 E-mail: jwork@kryton.com	•						
Lafarge North America 30600 Telegraph Rd, Ste 4000 Bingham Farms, MI 48025-5726	Website: http://www.lafargenorthamerica.com Contact: Ken Kazanis Phone: 248-594-1991 E-mail: ken.kazanis@lafarge-na.com		•	•				
Lanford Brothers Company Inc. PO Box 7330 Roanoke, VA 24019	Website: http://www.lanfordbrothers.com Contact: Patrick McDaniel Phone: 540-992-2140 E-mail: patm@lanfordbros.com				•			
Lehigh Cement Company/White Cement Div. 7660 Imperial Way Allentown, PA 18195-1016	Website: http://www.lehighwhitecement.com Contact: Larry Rowland Phone: 610-366-4600 E-mail: lrowland@lehighcement.com		•					
LRL Construction Co. Inc. PO Box 432 Tillamook, OR 97141	Website: http://www.lrlconstruction.com Contact: Denis Laviolette Phone: 503-842-5520 E-mail: info@lrlconstruction.com			•	•			
MacLean Engineering & Marketing Co. Ltd. 1000 Raglan St Collingwood, ON L9Y 3Z1, Canada	Website: http://www.macleanengineering.com Contact: Steve Czerny Phone: 705-445-5707 E-mail: sczerny@macleanengineering.com					•		
Mar-Allen Concrete Products Inc. 490 Millway Rd Ephrata, PA 17522-9528	Contact: Jeffrey L. Zimmerman Phone: 717-859-4921 E-mail: jlzimmerman@marallen.com				•			
The Marksmen Company 705 E Ordnance Rd, Suite 107 Baltimore, MD 21226-1760	Website: http://marksmenco.com/ Contact: Mark D. Miller Phone: 410-355-6080 E-mail: markmiller@marksmenco.com				•			
Mays Construction Specialties Inc. 2399 Riverside Parkway Grand Junction, CO 81505	Website: http://www.mays-mcsi.com Contact: Kyle R. Vanderberg Phone: 970-245-0834 E-mail: kvanderberg@mays-mcsi.com				•			
MDC Concrete Inc. 2010-A Harbison Drive #313 Vacaville, CA 95687-3900	Website: http://www.mdc-concrete.com/ Contact: Jesus Melecio Phone: 707-452-9388 E-mail: mdcbuilders@att.net			•	•			
Metro Testing Laboratories Ltd. 6991 Curragh Ave Burnaby, BC V5J 4V6, Canada	Website: http://www.metrotesting.ca Contact: Neil McAskill Phone: 604-436-9109 E-mail: nmcaskill@metrotesting.ca			•				
Mid American Gunite Pools Inc. 1607 Eastern Ave Covington, KY 41014-1325	Website: http://www.midamericanpools.com Contact: Patrick M. Brennan Phone: 859-581-8566 E-mail: pool1boss@fuse.net				•			
Minova North America 150 Carley Ct Georgetown, KY 40324-9303	Website: http://www.minovausa.com/ Contact: Bryan Pfaff Phone: 678-634-9626 E-mail: bryan.pfaff@minovaint.com							•

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		Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Mosites Construction Company 4839 Campbells Run Road Pittsburgh, PA 15205	Website: http://www.mosites.com Contact: Erik Bertrand Phone: 412-923-2255 E-mail: erikb@mosites.com				•			
Multicrete Systems Inc. 106 Devos Rd Winnipeg, MB R3T 5Y1, Canada	Website: http://www.multicretesystems.com Contact: Georg B. Nickel, P.Eng Phone: 204-262-5900 E-mail: gnickel@multicretesystems.com	•	•	•	•	•	•	•
The Nassal Company 415 W Kaley St Orlando, FL 32806-3942	Website: http://www.nassal.com Contact: Melissa Ruminot Phone: 407-648-0400 E-mail: mruminot@nassal.com			•	•			
National Gunite Inc. 111 Roosevelt Blvd Johnstown, PA 15906-2736	Website: http://www.nationalgunite.com Contact: Lee Taylor Phone: 814-533-5780 E-mail: ltaylor@nationalgunite.com			•				
Nationwide Shotcrete Inc. 23638 Lyons Ave, Ste 273 Newhall, CA 91321-2513	Website: http://nationwideshotcrete.com/ Contact: Jordan Harpole Phone: 661-799-3750 E-mail: nationwideshotcrete@yahoo.com			•	•			
Naumann Nature Scapes Inc. 1605 N Indian River Dr Cocoa, FL 32922	Website: http://www.naumannnaturescapes.com Contact: Roger Naumann Phone: 321-544-3377 E-mail: rnaumann@cfl.rr.com				•			
NBIS 800 Overlook III 2859 Paces Ferry Road Atlanta, GA 30339	Website: http://www.nbis.com Contact: Lisa McAbee Phone: 866-668-NBIS E-mail: lmcabee@nbis.com			•				
Neil O Anderson & Associates 50 Goldenland Ct, Ste 100 Sacramento, CA 95834	Website: http://www.noanderson.com Contact: Robert Holmer, PE Phone: 916-928-4690 E-mail: rob.holmer@noanderson.com			•				
New Line Skateparks Inc. 101-6247 205th Street Langley, BC V2Y 1N7, Canada	Website: http://www.newlineskateparks.com Contact: Tim Dubbin Phone: 604-530-1114 E-mail: tim@newlineskateparks.com			•	•			
Normet Americas Inc. 19116 Spring St Union Grove, WI 53182-9602	Website: http://www.normet.fi Contact: Chris Gause Phone: 262-878-5760 E-mail: chris.gause@normet.fi	•	•	•		•		
Northwest Cascade Inc. PO Box 73399 Puyallup, WA 98374	Website: http://www.nwcascade.com Contact: Douglas Watt Phone: 253-848-2371 E-mail: dougwatt@nwcascade.com				•			
Olin Engineering Inc. 15622 Computer Ln Huntington Beach, CA 92649-1608	Website: http://www.olinpump.com Contact: David O. Swain Phone: 714-897-1230 E-mail: dave@olinpump.com					•		
Olympic Pool Plastering & Shotcrete 2850 Simpson Circle Norcross, GA 30071	Contact: Shawn Still Phone: 770-409-1125 E-mail: smstill@olympicpool.net			•	•			•
Osco Gunite & Mudjacking Ltd. 5920 98 St NW Edmonton, AB T6E 3L5, Canada	Website: http://www.shotcreting.com Contact: Larry Hnatiuk Phone: 780-469-1234 E-mail: osco@mudjacking.com				•			

Name/Address	Contact information	Specialties: Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Palmetto Gunite Construction Company Inc. PO Box 388 Ravenel, SC 29470-0388	Website: http://www.palmettogunite.com Contact: Thomas A. Hendricks Phone: 843-889-2227 E-mail: thendpalgun@cs.com				•			
PCI Roads LLC 14123 42nd St NE Saint Michael, MN 55376-9564	Website: http://www.pciroads.com Contact: Dave Graham Phone: 763-497-6100 E-mail: dgraham@pciroads.com				•			
Pool Engineering Inc. 1201 N Tustin Ave Anaheim, CA 92807-1646	Website: http://www.pooleng.com/ Contact: Ron Lacher Phone: 714-630-6100 E-mail: ronl@pooleng.com			•	•			
Power Shotcrete Shoring Ltd. 109-8918 Holt Rd Surrey, BC V4N 3S2, Canada	Website: http://www.powercivil.ca Contact: Kirk Gilchrist Phone: 604-597-1112 E-mail: nadink@powercivil.ca			•	•			
Preload Inc. 49 Wireless Blvd, Suite 200 Hauppauge, NY 11788-3946	Website: http://www.preload.com Contact: Donald Cameron Phone: 631-231-8100 E-mail: dgc@preloadinc.com				•			
Prestige Concrete Products 7228 Westport Pl West Palm Beach, FL 33413-1683	Website: http://www.prestige-gunite.com Contact: Greg McFadden Phone: 561-478-9980 E-mail: gwmcfadden@prestige-concrete.com	•	•	•	•			•
ProShot Concrete Inc. 4158 Musgrove Dr Florence, AL 35630-6396	Website: http://www.proshotconcrete.com Contact: Patrick A. Mooney Phone: 256-764-5941 E-mail: patm@proshotconcrete.com				•			
Pullman-Shared Systems Technology, Inc. 127 Salem Ave West Deptford, NJ 08086-2076	Website: http://www.pullman-services.com/ Contact: Doug Rose Phone: 856-449-0902 E-mail: drose@pullman-services.com				•			
Putzmeister Iberica S A Camino de Hormigueras 173 Madrid 28031, Spain	Website: http://www.putzmeister.es/shotcrete Contact: Christine Krauss Phone: 011-34914288097 E-mail: kraussc@putzmeister.es					•		
Putzmeister Shotcrete Technology 1733 90th St Sturtevant, WI 53177-1805	Website: http://www.allentownshotcrete.com/ Contact: Patrick Bridger Phone: 262-886-3200 E-mail: bridgerp@putzam.com					•		
The Quikrete Companies 3490 Piedmont Rd NE Atlanta, GA 30305-1743	Website: http://www.quikrete.com/Shotcrete Contact: Dennis Bittner Phone: 412-759-1333 E-mail: dbittner@quikrete.com		•					•
Quikspray, Inc. PO Box 327 Port Clinton, OH 43452	Website: http://www.quikspray.com Contact: T. Park McRitchie Phone: 419-732-2611 E-mail: park@quikspray.com					•		
Ram Construction Services 13800 Eckles Rd Livonia, MI 48150-1041	Website: http://www.ramservices.com Phone: 734-464-3800 E-mail: mmcnab@ramservices.com			•	•			
Ram Jack of Charlotte, LLC PO Box 2991 Huntersville, NC 28070-2991	Website: http://www.ramjackcharlotte.com Contact: Mark Beckham Phone: 704-892-2900 E-mail: markramjack@bellsouth.net				•			

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		Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
REED Shotcrete Equipment 13822 Oaks Ave Chino, CA 91710-7008	Website: http://www.reedpumps.com Contact: Mike Newcomb Phone: 909-287-2100 E-mail: mike.newcomb@reedmfg.com					•		
Repcrete Concrete Repairs & Cont. Co. PO Box 45962 Abu Dhabi, United Arab Emirates	Website: http://www.repcreteuae.com Contact: Khaled Naddeh Phone: 01197126336128 E-mail: repcrete@emirates.net.ae				•			
Restek Inc. 6601 Boucher Dr Edmond, OK 73034-8582	Website: http://www.restekinc.net/ Contact: Ellery N. Brown Phone: 405-330-3950 E-mail: restek@flash.net				•			
RG Johnson Company Inc. 25 S College St Washington, PA 15301-4821	Website: http://www.rgjohnsoninc.com Contact: Richard E. Adasiak Phone: 724-222-6810 E-mail: rich@rgjohnsoninc.com				•			•
Riverdale Mills Corp. PO Box 200 Northbridge, MA 01534-0200	Website: http://www.riverdale.com Contact: Christine Albone Phone: 800-762-6374 E-mail: lrwalsh@riverdale.com						•	
Royal Enterprises 30622 Forest Blvd Stacy, MN 55079-8005	Website: http://www.royalenterprises.net Contact: Steve Bahe Phone: 651-462-6918 E-mail: sbahe@royalenterprises.net						•	
San Joaquin Gunite 5868 E Mustang Clovis, CA 93619	Website: http://www.sanjoaquingunite.com Contact: Scott Santellan Phone: 559-285-8965 E-mail: h55quad@aol.com				•			•
Schnabel Foundation Company 2950 S Jamaica Ct, Ste 107 Aurora, CO 80014-2686	Website: http://www.schnabel.com Contact: Todd Duncan Phone: 303-696-7268 E-mail: todd@schnabel.com				•			
Shotcrete Auckland Ltd. PO Box 64439 Auckland, NS 2014, New Zealand	Contact: Glenn Tira Phone: 011-6421701807 E-mail: glenn@shotcrete.co.nz	•			•	•	•	•
Shotcrete Helmet PO Box 430 Stn Main Paris, ON N3L 3T5, Canada	Website: http://www.shotcretehelmet.com Contact: The St. George Company Phone: 519-442-2046 E-mail: info@shotcretehelmet.com					•		
Shotcrete Technologies Inc. PO Box 3274 Idaho Springs, CO 80452-3274	Website: http://www.shotcretetechnologies.com Contact: Kristian Loevlie Phone: 303-567-4871 E-mail: kristian@shotcretetechnologies.com	•	•	•	•			
Sika Corporation 201 Polito Ave Lyndhurst, NJ 07071-3601	Website: http://www.sikaconstruction.com Contact: Ketan Sompura Phone: 201-508-6698 E-mail: sompura.ketan@sika-corp.com	•	•					
Soil Nail Launcher Inc. 2841 North Ave Grand Junction, CO 81501-4918	Website: http://soilnaillauncher.com Contact: Tim Ruckman Phone: 970-210-6170 E-mail: tim@soilnaillauncher.com				•			
South Shore Gunite Pool & Spa, Inc. 7 Progress Ave Chelmsford, MA 01824-3606	Website: http://www.ssgpools.com Contact: Robert E. Guarino Phone: 800-649-8080 E-mail: rguarino@southshoregunitepools.com			•	•			

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Southwest Contracting Ltd. 9426 - 192nd Street Surrey, BC V4N 3R9, Canada	Website: http://www.swc.bc.ca Contact: Scott MacCara Phone: 604-888-5221 E-mail: admin@southwestcontracting.ca				•			
Southwest V-Ditch Inc. 3625 Placentia Ln Riverside, CA 92501-1119	Website: http://www.swvditch.com Contact: Bob Shepherd Phone: 951-781-4303 x1 E-mail: mail@swvditch.com				•			
SPB Torkret Ltd. sp z.o.o. spolka komandytowa, ul. Grabowa 8 Siekierki Wielkie Wielkopolska 62-025, Poland	Website: http://www.torkret.com.pl Contact: Wlodzimierz Czajka Phone: 486-189-7810 x2 E-mail: czajka@torkret.com.pl			•	•			
Spec Mix Inc. 1230 Eagan Industrial Rd, Suite 160 Eagan, MN 55121-1293	Website: http://www.specmix.com Contact: Leah Cory Phone: 651-994-7120 E-mail: nblohowiak@specmix.com					•		•
SprayForce Concrete Services Ltd. 10 Brander Ave NW Langdon, AB T0J 1X2, Canada	Website: http://www.sprayforceconcrete.com Contact: Jay Unruh Phone: 403-936-0178 E-mail: info@sprayforceconcrete.com			•	•			
Stone Valley Construction Inc. 132 Coaldale Rd Philipsburg, PA 16866-2333	Website: http://www.stone-valley.com Contact: Ken Knepp Phone: 814-342-7151 E-mail: kknepp@stone-valley.com			•	•			
Strata Mine Services 67925 Bayberry Dr Saint Clairsville, OH 43950-9132	Website: http://www.strataworldwide.com Contact: Jeff Hamrick Phone: 740-695-6880 E-mail: jhamrick@stratamineservices.com				•			
Structural Shotcrete Systems Inc. 12645 Clark St Santa Fe Springs, CA 90670-3951	Website: http://www.structuralshotcrete.com/index.html Contact: Jason Weinstein Phone: 562-941-9916 E-mail: jason1@structuralshotcrete.com				•			
StructureWerks 12600 Robin Ln, Ste 100 Brookfield, WI 53005-3124	Website: http://www.structurewerks.com Contact: Ross Preschat Phone: 262-781-4329 E-mail: rpreschat@structurewerks.com			•	•			
Subsurface Construction Company 1107 Fuller Street Raleigh, NC 27603	Website: http://www.subsurfaceconstruction.com Contact: Alex Smith Phone: 919-857-4609 E-mail: alex@subsurfaceconstruction.com				•			
Suburban Maintenance 16330 York Rd North Royalton, OH 44133-5551	Website: http://www.smciconstruction.com Contact: Eric Urdzik Phone: 440-237-7765 E-mail: eurdzik@smciconstruction.com				•			
Sunwest Gunite Co. 7045 Luella Anne Dr NE Albuquerque, NM 87109-3907	Website: http://www.sunwestguniteco.com Contact: Gary O'Canna Phone: 505-821-2549 E-mail: garyocanna@gmail.com			•	•			
Superior Gunite / JW Gunite Company 940 Doolittle Dr San Leandro, CA 94577-1021	Website: http://www.shotcrete.com Contact: Larry J. Totten Phone: 510-568-8112 E-mail: larryt@jwgunite.com				•			

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Name/Address	Contact information	Specialties: Admixtures	Cement/ Pozzolanic Matl	Consulting	Contractor	Equipment	Fibers	Shotcrete Materials/Mixes
Testing, Engineering & Consulting Services Inc. 235 Buford Dr Lawrenceville, GA 30046-4945	Website: http://www.tecservices.com Contact: James Glenn McCants III Phone: 770-995-8000 E-mail: tmccants@tecservices.com			•				
Texaloy Foundry Company Inc. PO Box 37 Floresville, TX 78114-0037	Website: http://www.texaloy.com Contact: Jack Rice Phone: 800-367-6518 E-mail: jrice@Texaloy.com					•		
Thiessen Team USA Inc. PO Box 40 Elko, NV 89803-0040	Website: http://www.thiessenteam.com Contact: James Schumacher/Jessica Florence Phone: 775-777-1205 E-mail: jschumacher@thiessenteam.com	•		•	•	•	•	•
Top Gun Commercial Gunite Of VA Inc. PO Box 1017 Gainesville, VA 20156-1017	Website: http://www.Topgun.ebb.net Contact: Russell H Ringler E-mail: fortopgun@aol.com				•			
Top Gun of Virginia Inc. 10017 Richmond Hwy Lorton, VA 22079-2421	Website: http://www.topgungunite.com/ Contact: Jon Slaunwhite Phone: 703-550-9207 E-mail: info@topgungunite.com				•			
Topcor Services Inc. 12025 Industriplex Blvd Baton Rouge, LA 70809-5131	Website: http://www.topcor.com Contact: James M. Baker Phone: 225-753-7067 E-mail: jbaker@topcor.com			•	•			
Torrent Shotcrete Structures Ltd. #207-53 West Hastings Street Vancouver, BC V6B 1G4, Canada	Website: http://torrentshotcrete.com/ Contact: Carl King Phone: 604-996-2219 E-mail: carlk@torrentshotcrete.com				•			
Truesdell Corporation 1310 W 23rd St Tempe, AZ 85282-1837	Website: http://www.truesdellcorp.com Contact: Kurt Clink Phone: 602-437-1711 E-mail: kclink@truesdellcorp.com				•			
U S Concrete Products LLC 16 Greenmeadow Dr, Ste 202 Timonium, MD 21093-3231	Website: http://www.uscproducts.com Contact: Edward Brennan Phone: 410-561-8770 E-mail: ebrennan@uscproducts.com	•	•	•				
Uretek ICR 8815 Neville Rd Colfax, NC 27235-9769	Website: http://uretekicr.com Contact: Brian Despain Phone: 336-992-0746 E-mail: bdespain@uretekma.com		•	•	•			
Vancouver Shotcrete & Shoring Inc. 19585 96th Ave, Unit 4 Surrey, BC V4N 4C5, Canada	Website: http://www.shotcreteshoring.com Contact: Rabi Gill Phone: 604-881-4898 E-mail: info@shotcreteshoring.com			•	•			
Western Shotcrete Equipment Inc. HC 1 Box 193 Fairdealing, MO 63939-9708	Website: http://www.wseshotcrete.com Contact: Joe Harpole Phone: 573-857-2085 E-mail: josephharpole@wseshotcrete.com					•		
Whiteside Construction Corporation 1151 Hensley St Richmond, CA 94801-2162	Website: http://www.wesconshotcrete.com Contact: David Whiteside Phone: 510-234-6681 E-mail: drw@whitesideconstruction.com				•			
Wildcat Concrete Services Inc. PO Box 750075 Topeka, KS 66675-0075	Website: http://wildcatcompanies.com/concrete.html Contact: Stuart R. Johnson Phone: 785-233-1400 E-mail: stuartj@wildcatconcrete.com				•			

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Williamstown Mining Inc. 733 Forever Ln Ligonier, PA 15658-2349	Website: http://www.williamstownmining.com Contact: Carmellio G. Faieta Phone: 817-891-5105 E-mail: carmelliofaieta@williamstownmining.com	•	•	•	•	•	•	•
WLH Construction Company 2000 W 60th Ave Denver, CO 80221-6631	Website: http://www.wlhconstruction.com Contact: Warren Harrison Phone: 303-347-8655 E-mail: wharrison@wlhconstruction.com				•			
Wurster Engineering & Construction 34 Carrie Dr Greenville, SC 29615-5611	Website: http://www.wursterinc.com Contact: Daryl Wurster Phone: 964-627-7751			•	•			
Xtreme Shotcrete 166 Woodside Ave Winthrop, MA 02152-2063	Website: http://xtremeshotcretema.com Contact: Michael Anthony Whitehead Phone: 617-846-3191 E-mail: whitehead0015@aol.com				•			

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A quarterly publication of the American Shotcrete Association

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CORPORATE MEMBERS

Subsurface Construction Company
www.subsurfaceconstruction.com
Raleigh, NC
Primary contact: Alex Smith
alex@subsurfaceconstruction.com

Georgia Gunite and Pool Company
Woodstock, GA
Primary contact: Tina Davis
tina@georgiagunite.com

Power Shotcrete Shoring Ltd
www.powercivil.ca
Surrey, BC, Canada
Primary contact: Kirk Gilchrist
nadink@powercivil.ca

Olympic Pool Plastering & Shotcrete
Norcross, GA
Primary contact: Shawn Still
smstill@olympicpool.net

GA & FC Wagman, Inc.
www.wagman.com
York, PA
Primary contact: Russ Ringler
rhringler@wagman.com

K & G Concrete Inc.
http://kgconcretepumping.com
Roseville, CA
Primary contact: Herman Keaven Guillory
keaven@kgconcretepumping.com

DBM Contractors, Inc.
http://dbmcm.com
Federal Way, WA
Primary contact: Sue Wolf
suew@dbmcm.com

Top Gun Commercial Gunite of VA Inc.
www.topgun.ebb.net
Gainesville, VA
Primary contact: Russell H. Ringler
fortopgun@aol.com

ATEK Fine Chemical Co. Ltd.
www.atekfc.com
Chungcheongbuk-do, NS, Korea
Primary contact: Mi-Jung Kim
hslee@atekfc.com

Apex Testing Laboratories, Inc.
www.apextestinglabs.com
San Francisco, CA
Primary contact: Abdel-Kader Khelifa
abdel@apextestinglabs.com

Mosites Construction Company
www.mosites.com
Pittsburgh, PA
Primary contact: Erik Bertrand
erikb@mosites.com

Arco Gunite, Inc.
Orange, CA
Primary contact: Tammy Counoupas
arcoguniteinc1976@yahoo.com

Shotcrete Auckland Ltd.
Auckland, NS, New Zealand
Primary contact: Glenn Tira
glenn@shotcrete.co.nz

CORPORATE ADDITIONAL INDIVIDUALS

Richard Werth
Strata Mine Service
Saint Clairsville, OH

INDIVIDUALS

Bill Drudy
RFI Construction Products, Inc.
Farmingdale, NY

Jake Mitchell
Mitchcon Pty Ltd.
Brooklyn, NS, Australia

STUDENTS

Ernesto Guevara Ortiz
Ottawa, ON, Canada

INTERESTED IN BECOMING A MEMBER OF ASA?

Find a Membership Application on page 95, and read about the benefits of being a member of ASA at www.shotcrete.org/pages/membership/benefits.htm.

AMERICAN SHOTCRETE ASSOCIATION

AMERICAN SHOTCRETE ASSOCIATION

38800 Country Club Dr., Farmington Hills, MI 48331
Phone: (248) 848-3780 Fax: (248) 848-3740
E-mail: info@shotcrete.org Web site: www.shotcrete.org

MEMBERSHIP APPLICATION

Name ______________________ Title ______________________

Company ______________________ Sponsor (if applicable) ______________________

Address ______________________

City / State or Province / Zip or Postal Code ______________________

Country ______________ Phone ______________ Fax ______________

E-mail ______________________ Web site ______________________

Please indicate your category of membership:

❑ Corporate	$750	*NOTE: Dues are not deductible as charitable contributions for tax purposes, but may be deductible as a business expense.*
❑ Individual	$250	
❑ Additional Individual from Corporate Member	$100	
❑ Employees of Public Authorities and Agencies	Free	
❑ Nozzleman	$50	
❑ Retired	$50 (For individuals 65 years or older)	
❑ Student	Free (Requires copy of Student ID card or other proof of student status)	

Payment Method:

❑ MC ❑ Visa ❑ Check enclosed (U.S. $)

Card# ______________________ Expiration date ______________

Name on card ______________________ Signature ______________________

Company Specialties—Corporate Members Only

Company Specialties are searchable in the printed and online Buyers Guide.

Admixtures
❑ Accelerating
❑ Air Entraining
❑ Foaming
❑ Retarding
❑ Shrinkage Compensating
❑ Special Application
❑ Stabilizing
❑ Water Proofing
❑ Water Reducing-Accelerate
❑ Water Reducing-High Range
❑ Water Reducing-Mid Range
❑ Water Reducing-Normal
❑ Water Reducing-Retarding
❑ Water Repellent

Cement/Pozzolanic Materials
❑ Cement-Blended
❑ Cement-Portland
❑ Cement-White
❑ Fly Ash
❑ Ground/Granulated Slag
❑ Metakaolin
❑ Pozzolan
❑ Silica Fume-Dry
❑ Silica Fume-Slurry

Consulting
❑ Design
❑ Engineering
❑ Forensic/Troubleshooting
❑ Project Management
❑ Quality Control Inspection/Testing
❑ Research/Development
❑ Shotcrete/Gunite
❑ Skateparks

Contractors
❑ Architectural
❑ Canal Lining
❑ Culvert/Pipe Lining
❑ Dams/Bridges
❑ Domes
❑ Flood Control/Drainage
❑ Foundations
❑ Grouting
❑ Lagoons
❑ Mining/Underground
❑ Parking Structures
❑ Pumping Services
❑ Refractory
❑ Repair/Rehabilitation
❑ Residential

Contractors, contd.
❑ Rock Bolts
❑ Rock Carving
❑ Seismic Retrofit
❑ Sewers
❑ Skateparks
❑ Slope Protection/Stabilization
❑ Soil Nailing
❑ Storage Tanks
❑ Structural
❑ Swimming Pools/Spas
❑ Tunnels
❑ Walls
❑ Water Features

Equipment
❑ Accessories
❑ Adaptors
❑ Air Vibrators
❑ Bowls
❑ Clamps
❑ Compressors
❑ Couplings
❑ Feeder/Dosing
❑ Finishing
❑ Grouting

Equipment, contd.
❑ Guide Wires
❑ Gunning Machines
❑ Hoses
❑ Mixers
❑ Nozzles
❑ Pipe/Elbows/Reducers
❑ Plastering
❑ Pre-Dampers
❑ Pumps
❑ Robotic
❑ Safety/Protection
❑ Silo Systems
❑ Valves
❑ Wear Plates

Fibers
❑ Carbon
❑ Glass
❑ Steel
❑ Synthetic

Shotcrete Materials/Mixtures
❑ Dry Mix
❑ Steel-Fiber Reinforced
❑ Synthetic-Fiber Reinforced
❑ Wet Mix

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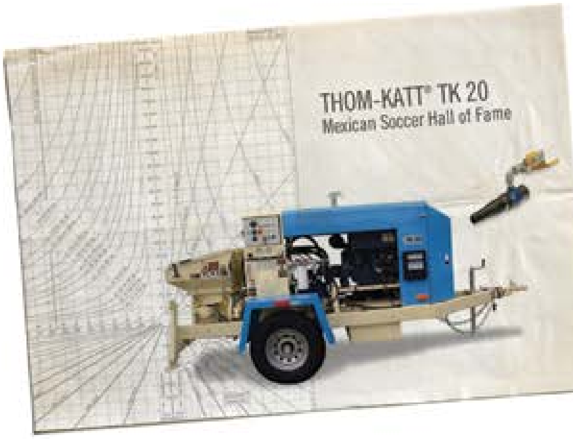
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