Shotcrete MAGAZINE

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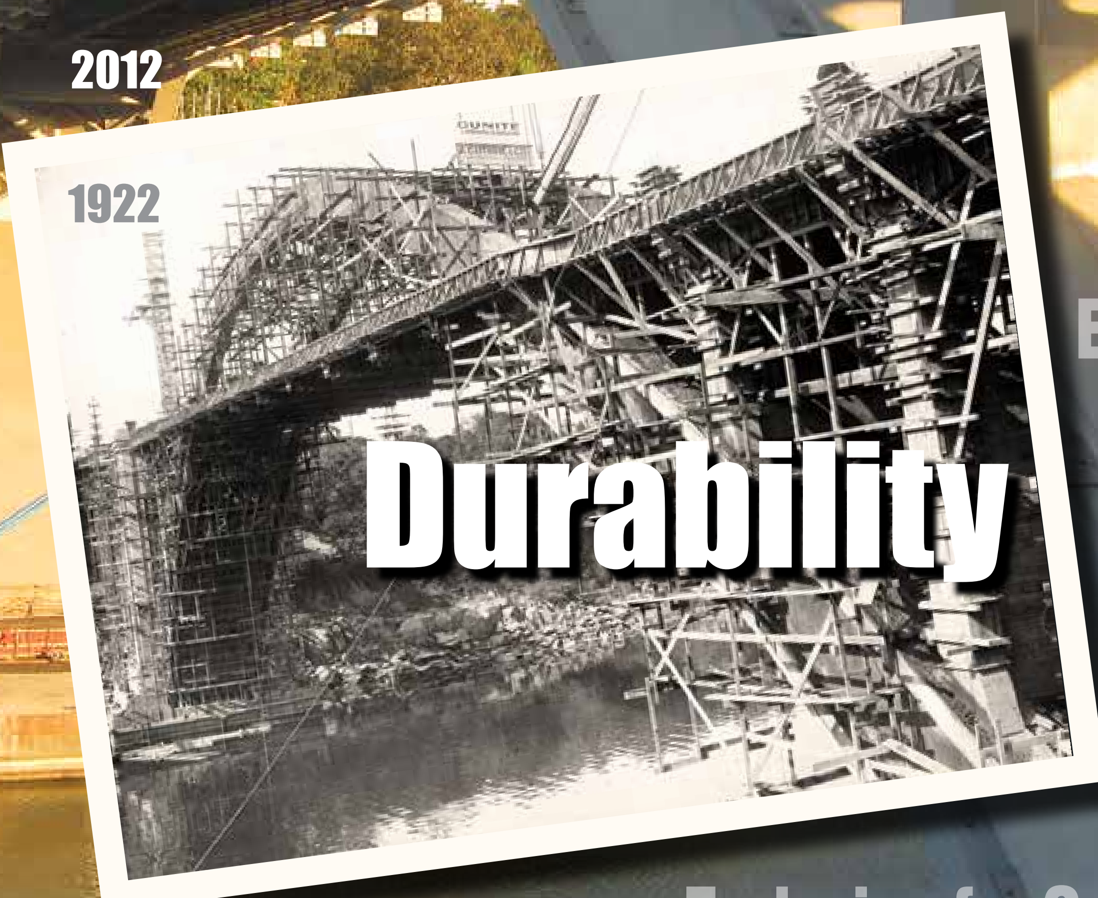

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Shotcrete MAGAZINE

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Features

Departments

On the cover: The Oregon City Arch Bridge—2013 Outstanding Repair & Rehabilitation Project, previously published in Shotcrete *magazine, Winter 2014*

The Plan

By Marcus H. von der Hofen

I hope everybody had a good previous year and is looking forward to a successful new one. ASA has been very busy thanks to our Past President, new Executive Director Charles Hanskat, and the rest of the committee members, most of whom have contributed for years. I hope members are aware that over the past year, ASA has developed a focused Strategic Plan. Some goals are things you have probably heard but many of them are more ambitious and exciting than ever.

Our Mission to provide training, qualification, certification, and education and to increase acceptance, quality, and safe practices of the shotcrete process has really just begun. To achieve these goals, we have implemented a four-part strategic breakdown that focuses on Professional Development, Outreach, Credibility, and Organizational Strength.

Professional Development

Our education program has been very successful in helping nozzlemen achieve their goal of becoming ACI Certified Nozzlemen; however, we realize that nozzlemen are only one component of the process. We cannot overlook the need for qualified inspectors and contractors and develop the resources they need to be credible and proficient to the industry's consumers. As important as these needs are, it is just as critical to fill the void in educational material for engineers/specifiers. We need more promotion of our AIA continuing education courses to help more shotcrete projects become a reality from the people who could and should be designing them. Many with whom I have spoken clearly lack confidence in our process because they haven't been provided with viable and credible information.

Outreach

Let's get this information in the hands of those who need it. Our goal is to strengthen or create relationships with groups that also provide support to the concrete industry. By doing this we can tailor our educational programs to complement the existing programs. After a century of shotcrete, it is high time that we help higher education bring the process to students as part of their concrete curriculum.

Credibility

We need to have grass roots involvement with students and support their education with R&D. A strengthened role with the American Concrete Institute, AASHTO, ASTM International, and other standards publications will help put our process in the conversation it deserves. By enhancing our position with recognized contractor and craftsman credentials developed and implemented in the next 2 years, the choice of shotcrete or cast-in-place concrete could become the simple option it should be.

Organization Strength

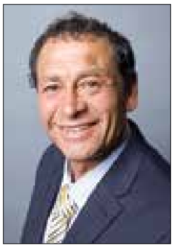
These are the goals—without question, they will help our industry and they are achievable. I am asking you as members to step up to the plate and get involved. More than ever, we need you to join the committees and grow our membership. Without your involvement—both with time and money—the ASA volunteer organization cannot continue to meet these challenges. I think someone once said, "Ask not what shotcrete can do for you, but what you can do for shotcrete," or something like that.

I have only scratched the surface of what our Strategic Plan entails and look forward to seeing you—the membership—help make it a reality this coming year.

ASA Education Committee

Knowledge is the key element to effecting change

By Oscar Duckworth



Well, here I am, getting comfortable at my new post as the ASA Education Committee Chair.

It has been a busy time for me. Although the goal of education has always been an important component to the mission statement of the American Shotcrete Association, recently, education and training have been earmarked as key goals in the ASA Strategic Plan.

Historically, the ASA Education Committee's efforts have been channeled through precertification Nozzleman education sessions, on-site 1-hour seminars, and articles in *Shotcrete* magazine as the primary tools of education.

Through strong industry leadership from committed membership involvement, ASA has a new opportunity to communicate critical knowledge with an important segment of the shotcrete industry: the inspection community.

Many of us are familiar with the common ritual of "on-job educating" inspection personnel. Currently, a general lack of inspector specific knowledge exists regarding shotcrete placement practices. Although inspector education and training programs are common in the concrete industry, no similar program is currently available for shotcrete.

Due to the strong growth of shotcrete construction, our industry is experiencing an acute need for knowledgeable on-site inspectors

Through the diligent efforts of the members of the Education Committee Inspector Training Task Group, we are completing the first-ever Shotcrete Inspector training program. This comprehensive program has been in development for nearly 5 years by a cross section of shotcrete industry experts, engineers, and educators. The proposed program covers over 40 critical elements of shotcrete placement that on-site inspectors must know to properly evaluate and sign off on acceptance documents.

Due to the strong growth of shotcrete construction, our industry is experiencing an acute need for knowledgeable on-site inspectors. Contractors and specifiers frequently face challenges when a lack of knowledge from the building official or inspector is either limiting the use of shotcrete or creating potential litigious situations. Currently, deputy (on-site) inspection personnel can be authorized to generate and sign off shotcrete placement compliance, but may lack sufficient insight on acceptable placement procedures or shotcrete industry reference standards.

Although an inspector may be thoroughly experienced in the inspection of concrete work, it is necessary to have an understanding of the specific elements of shotcreting, the equipment used, terminology, and required procedures when using the shotcrete process.

Upon completion of the program, inspectors should have:

- A fundamental understanding of the wet- and dry-mix shotcrete process;
- Current knowledge of ACI reference material and other industry standards pertaining to acceptable shotcrete placement;
- Industry-specific knowledge to determine if materials and methods used by the crew meet shotcrete project specifications; and
- Sufficient insight to recognize satisfactory application techniques, as well as actions which could lead to a poor-quality product.

Profile of individuals who may benefit from this program:

- Concrete Construction Inspectors or Transportation Construction Inspectors;
- ACI Concrete Field Testing Technicians–Grade 1;
- Engineers or specifiers who desire or are required to possess additional education to properly inspect shotcrete operations on projects; and
- Building officials who desire further knowledge of acceptable shotcrete placement methods.

The ASA Inspector training program presents an overview on placement techniques, finishing, curing, testing, equipment, and safety as it relates to the building official or inspector. Attendance at this session may satisfy the mandatory education session requirement for individuals wishing to pursue certification through the proposed ACI Shotcrete Inspector Certification Program (currently a work in progress), or similar program which may require an industry-specific education and training element. An ASA Inspector training document is the next phase of the inspector program. As previously stated, current reference materials are not specific to the inspection of shotcrete. This new document and the inspector training program will fill this need.

The first-ever Shotcrete Inspector training course was unveiled at World of Concrete 2015 in Las Vegas, NV, to an enthusiastic audience. The 8-hour course covered material derived from the draft Inspector document and was well received, providing charter participants a forward view of what is likely to be the future of shotcrete inspection education. ASA hopes to continue to offer several regional classes around the country this year. Look for more information from our online Calendar (**www.shotcrete.org/pages/news-events/calendar.htm**) as well as our monthly eNewsletter, "What's in the Mix." Sign up today if you are not already receiving these complimentary resources by visiting **www.shotcrete.org/pages/products-services/shotcrete-magazine-subscribe.htm**.

An important component to the ongoing growth of shotcrete will be the ability to share knowledge with all of the members of the industry. Although these efforts may not effect change overnight, they are certainly a step in the right direction.

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The Next Season

By Charles S. Hanskat, PE, ASA Executive Director

As the seasons change from winter to spring this year, ASA is undergoing major changes, too. To implement the Strategic Plan we adopted late last year, the Board decided that a full-time Executive Director with experience in shotcrete contracting and design, as well as association involvement, was essential to move our association forward. It was a great honor to be chosen by the Board to fill the new position of Executive Director. With my 37 years of experience in the shotcrete and concrete industry, I will also be able to provide our members with technical support for your questions about shotcrete.

I've always enjoyed working in the construction business. From my early days as a tradesman in the field, through becoming a professional engineer and running departments, regional offices, and then my own firms, I have learned a lot from all the construction people around me. We build things that make people's lives better…for a long time. My 25 years with design-build specialty contractors gives me a valuable perspective on how design, specifications, project management, and most importantly the field team have to work together to actually build the structures envisioned by the owners.

I'm stepping into the Executive Director role with a well-established, smoothly operating association. My sincere thanks to Mark Campo, who has been the administrative Executive Director for the last 2 years. Also, thanks to Alice McComas, our full-time Program Coordinator. Mark and Alice have allowed our volunteer officers and committee chairs to focus on their tasks to improve the organization while handling the administrative and routine organizational duties that keep our group running.

As I step into the role of Executive Director, I want to get more of our members actively engaged in our activities. We're pursuing new learning seminars; new certification opportunities; and outreach to owners, architects, engineers, general contractors, and others who need to understand the benefits of shotcrete in creatively building with concrete. As ASA members, your help with that will let us extend the reach of shotcrete.

Recent actions by our Board and Committees include President Marcus von der Hofen re-establishing the Underground Committee with experienced engineers and contractors. We are evaluating rebranding ASA in coordination with our new Strategic Plan. Our Membership Committee is investigating ways to provide a higher level of service to our members. The Pool & Recreational Shotcrete Committee continues to develop position papers to help quantify good practice in the industry. The Education Committee is developing a Shotcrete Inspector training session and the Safety Committee continues work on our Safety Guidelines. We're also developing a Contractor Qualification program to help specifiers who want to get verified experience on their shotcrete projects.

Our committees are the lifeblood of our activities and can always use more active member participation. If you aren't currently a committee member, please consider becoming one. We have standing committees for Education, Safety, Pool & Recreational Shotcrete, Marketing, Membership, and Publications. You can find the missions and current chairs of our committees at **www.shotcrete.org/pages/membership/committees.htm**.

These are exciting times for ASA, and I'm really excited to be a part of the leadership of our group. Feel free to contact me at any time. I'm also glad I can devote my full time and energy to advancing our strategic goals and fulfilling our Vision—"Structures built or repaired with the shotcrete process are accepted as equal or superior to cast concrete."

Durability and Exposure Conditions of Cementitious Materials

Deterioration Mechanisms

By Jonathan E. Dongell

There is a substantial amount of literature to be found regarding specific types of deterioration of concrete or shotcrete placed in various exposure conditions. This paper presents an introduction and methodical view of mass transport and its role in various exposure conditions given the presence of sufficient moisture. A simplified lineal-progression chart showing the various mass transport-induced deterioration mechanisms that facilitate deterioration is introduced. The overall objective of this article is to offer a simplified interpretation of the difficult concepts of mass transport and deterioration mechanisms.

Material-Related Contributing Factors

For a cementitious material placed in an exposure condition that is considered to be aggressive, there is a direct correlation between the susceptibility of that material and the rate of deterioration. Therefore, while this article deals only with mass transport and mechanisms of deterioration, it must be stated that mixture designs that minimize permeability and construction practices that provide uniformity in density and consolidation and mitigate cracking and other defects are key factors in producing a durable cementitious material. Additionally, the use of durability enhancers (pozzolanic or polymeric) within the mixture design, or the implementation of appropriate post-placement protective measures, help to ensure that the structure remains sound and achieves its anticipated service life.

Physical-Induced Deterioration versus Mass Transport-Induced Deterioration

Typically, the deterioration of a cementitious structure is the result of a multi-mechanism phenomenon. Freezing-and-thawing deterioration, for example, is often thought of as strictly deterioration by expansion and contraction of the material due to temperature gradient; however, accelerated damage can occur due to mass transport mechanisms and accompanied deleterious reactions. Mass transport allows moisture, salt, or other deleterious ions to move into, out of, and within the matrix of the cementitious structure. Salts can precipitate out of solution or crystallize, filling voids, cracks, and space around aggregate created by expansion and contraction. This filling of matrix space creates restriction, which increases internal stress upon further expansion and contraction. Associated stress-induced cracking accelerates the rate of deterioration of the structure. Mass transport may also provide the means by which deleterious ions enter the matrix, or facilitate the localized buildup of certain ions, which in turn may initiate secondary deleterious reactions.

Mass Transport

In general, the term "mass transport" as it relates to concrete is used to describe the overall mechanism by which matter is moved into, out of, within, or through the cementitious matrix. While mass transport mechanisms can proceed wherever water or sufficient moisture is present, whether or not matter is present in solution to transport, it is nevertheless the presence of deleterious material (salts or ions) or the existence of some chemical gradient between the water and cementitious material that is of concern. Therefore, mass transport is typically thought of as a combination of both water or moisture and material in solution. Mass transport can be divided into two main transport mechanisms of "convection" or "wicking" (refer to Fig. 1).

Convection

Convection is the transport of a material in solution by **diffusion** and **advection**. Diffusion is a transport mechanism resulting in the random spreading or mixing of material in solution. Advection is a transport mechanism caused by a directional bulk motion of fluid (water or moisture) resulting in the directional transport of material in solution. For example: if dye were poured into a river, advection would be the force (in this instance hydraulic force) carrying the dye downstream via bulk motion, and the spreading of the dye plume outward in an ever-

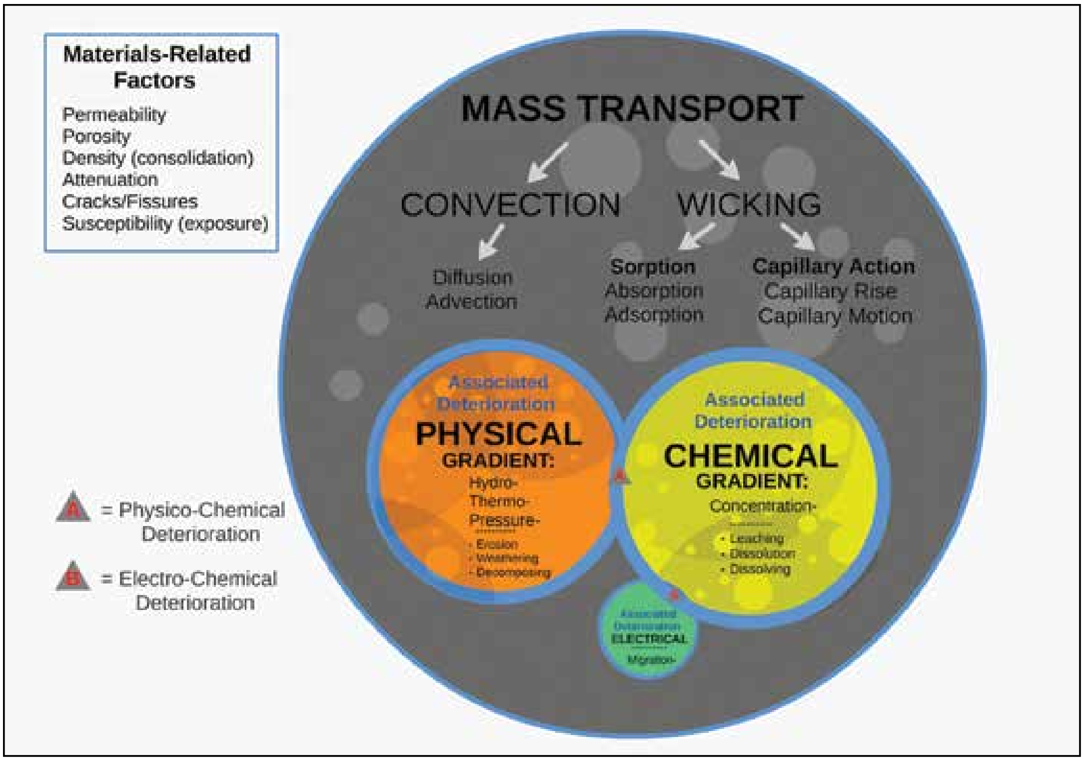

Fig. 1: Deterioration mechanism of a water contact environment

growing random fashion would be diffusion. In Fig. 2, an 8 in. (200 mm) pre-saturated concrete cylinder is placed in a bucket with 9 in. (230 mm) of standing water. The resulting convection transport mechanism is due to concentration gradient of (x) ions. Subsequent random spreading of the (x) ions is diffusion due to a chemical concentration gradient.

Wicking

Wicking is the movement of water or moisture and the transport of the material in solution by **sorption** and **capillary action**. Sorption is the transport of water, moisture, and material in solution by the combination of absorption and adsorption (refer to Fig. 2). Absorption is the permeation of water or moisture and material in solution into a dry or under-saturated cementitious matrix. This process can also be reversed, from a wet cementitious material to a dry or under-saturated soil. Adsorption is the physical adhesion of atoms, ions, or molecules to the compounds and solid surfaces within the cementitious matrix.

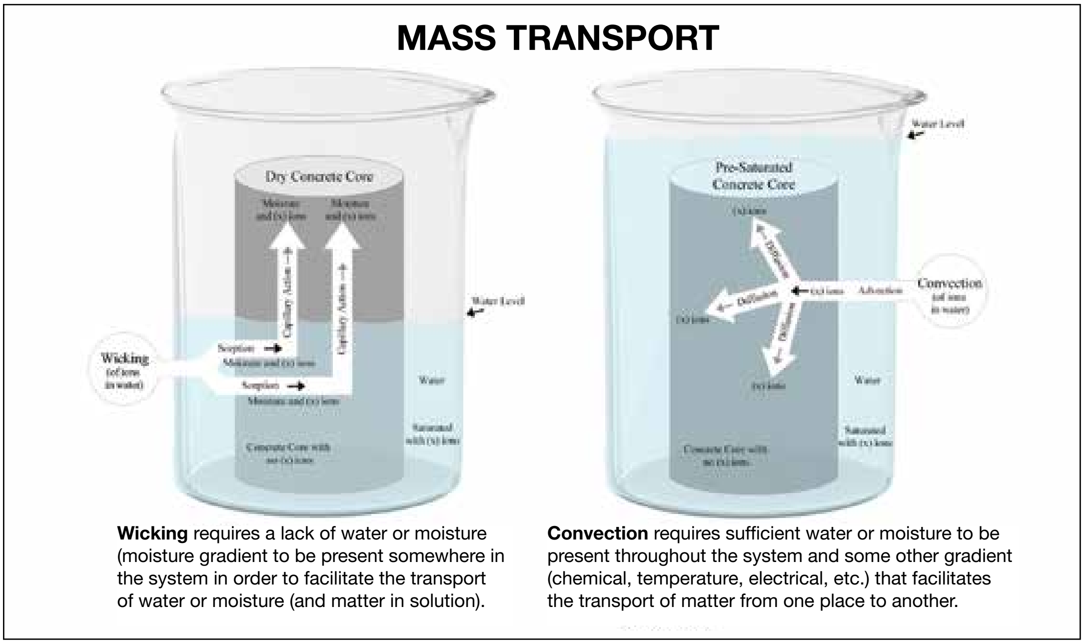

Fig. 2: Deterioration—transport mechanisms

Capillary action is the transport of water or moisture and material in solution by the forces of capillary motion and capillary rise. In general, this is the ability of water or moisture and material in solution to transport through narrow passages without the assistance of gravity or bulk motion. In Fig. 2, an 8 in. (200 mm) dry concrete cylinder is placed in a bucket with 4 in. (100 mm) of standing water; the water is wicked into the cementitious matrix. This is mainly due to sorptivity. The water or moisture and material in solution, however, continue to slowly climb upward against gravity; this upward permeation is mainly due to capillary action.

Combined Mechanisms

Not all attacks on concrete or shotcrete include mass transport as a contributing factor. While physical gradients, chemical gradients, electrical gradients, and combinations of these were placed within the overall sphere of mass transport deterioration mechanisms (refer to Fig. 1), this may not always be technically correct. For example, freezing and thawing could be considered solely a physical deterioration, and a sphere could be added to the diagram that is outside of (but still linked with) the mass transport sphere. However, for cementitious materials exposed to water or moisture contact, mass transport mechanisms often initiate, facilitate, and govern the rate at which deterioration proceeds. In other words, if there was no water or moisture present, there would be no mass transport mechanism, and there would be no deterioration.

Physicochemical

Deterioration caused by the physical action of erosion, weathering, or decomposition does not require a mass transport mechanism to proceed. However, a cementitious material placed in a water-contact environment or exposed to cycles of wetting and drying can experience a physicochemical attack. The combination of physical attack (abrasion, weathering, and so on) and chemical attack (leaching, dissolution, dissolving, or formation of concentrated areas of salts or alkalis) is facilitated by mass transport mechanisms. With salt weathering, for example, there is mass transport of salts into a cementitious matrix, but the attack may be considered strictly a physical attack as it results from the precipitation of salts within the matrix without necessarily the dissolution of the cementitious components to drive the degradation. In either instance, a mass transport mechanism facilitates the attack. The attack is considered a "physical salt attack" form of deterioration, made possible by a physicochemical transport mechanism.

Electrochemical

Electrochemical transport is a migration of electrons or ions through solution. This mechanism plays an important role in maintaining (protecting) or breaking down (destroying) the passivity layer on and around all embedded steel reinforcement. Except for the electrochemical migration associated with steel reinforcement, electrochemical gradients within cementitious materials typically cause migration of material in solution on the scale of millimeters.

Other Terms and Definitions

- Decompose—break down into components, or to separate into constituents or elements
- Deteriorate—to decompose, decay, breakdown, or crumble
- Dissolution—to extract chemically or preferentially remove material into a solution
- Dissolve—to disintegrate a material chemically into a solution, or to break apart
- Etch—to physically or chemically carve or engrave into the surface of a material
- Leach—the loss of mineral and organic solutes due to percolation from a material
- Migration—a motion of material in solution, distinct from diffusion, due to an electrical-applied force or electrical gradient

Jonathan E. Dongell *is current Director of Research & Development, Pebble Technologies, Scottsdale, AZ. Dongell has worked in concrete construction and with cementitious materials spanning over 30 years. His roles have included technician, superintendent, manager, contractor, and President. He was Past President, Whitestone Cement Company, Scottsdale, AZ (1998-2005) and Universal White Cement Co, Inc., Glendale, AZ (1992-1998). He is a member and past Chair of ACI Committee 524, Plastering, and is a member of ACI Committees 201, Durability of Concrete; 225, Hydraulic Cements; 232, Fly Ash in Concrete; 308, Curing Concrete; 350, Environmental Engineering Concrete Structures; and 555, Concrete with Recycled Materials. Dongell also serves on the ACI Concrete Research Council (CRC) and the ASA Pool & Recreational Shotcrete Committee. He is a voting member of ASTM International main committees and several subcommittees, including C4.01, Cement, Lime, Gypsum, and C4.02, Concrete and Aggregates. Dongell is the author of several books, including* The Durability of Cementitious Materials in a Water Contact Environment. *He is an inventor and holds three patents on cementitious materials. Dongell is a designated expert witness in the fields of cement, concrete, stucco/plaster, and water chemistry. He was the recipient of the Del Bloem Distinguished Service Award in 2008.*

Durability Investigation of Ultra-Rapid Strength-Gain Dry-Mix Shotcrete

By Nicolas Ginouse and William Clements

It has already been shown that rapid strength-gain dry-mix shotcrete using calcium sulfoaluminate (CSA) cement and providing about 2900 psi (20 MPa) after only 2 hours can be effectively produced and placed in mining applications (Reny and Clements 2013). As already discussed in several papers (Reny and Ginouse 2014; Lemay et al. 2014), the use of such rapid strength-gain dry-mix shotcrete can be a very efficient and robust solution to provide ultra-rapid support and reduce the mining/tunneling cycle by reaching the re-entry criteria much faster than with traditional portland cement-based dry-mix shotcrete using set accelerators.

In this context, the use of ultra-rapid strength-gain shotcrete appears to be a very attractive solution for emergency repairs in civil applications, where rapid strength-gain materials such as mortars or concretes are already employed to meet shortened construction schedules due to restricted lane closure times on bridges and roadways and restricted access time in tunnels. However, the use of rapid strength-gain repair materials is still a relatively new practice, and a practice that has not been fully investigated with respect to the durability of these repair materials even if several papers covering this topic have already been published (Barde et al. 2006; Garcia 2014). To develop a durable rapid strength-gain dry-mix shotcrete for emergency repairs, King Packaged Materials Company, Burlington, ON, Canada (King), conducted a testing program focused on certain durability properties of CSA cement-based dry-mix shotcrete. Therefore, the intent of this article is to present the preliminary results of this investigation.

Materials and Methods

Even though the cement chemistry and the hydration process controlling the rapid strength development of CSA cement-based materials have been the topic of several scientific studies (Juenger et al. 2011; Pelletier et al. 2010; Bernardo et al. 2006), the durability of such alternative cementitious materials is still under investigation. To investigate the durability properties of rapid strength-gain dry-mix shotcrete using CSA cement-based binder further, the testing program was divided into two phases.

The first phase of the testing program consisted of selecting three candidate mixture designs using the equivalent mortar method. As mentioned in Lemay (2013), this method is very useful for conducting preliminary optimization of early-age strengths for dry-mix shotcrete formulas because it allows the user to work on mortar mixtures having the same total specific area as the dry-mix shotcrete mixtures. Because mortars do not contain coarse aggregate, the equivalent mortar method first involves calculating the amount of surface area provided by the coarse aggregate in the candidate shotcrete/concrete mixture design. Then the surface area provided by the coarse aggregate is replaced by the equivalent surface area in the form of fine aggregate in the equivalent mortar. Using the equivalent mortar method allows for close approximation of the early-age strength development between the candidate shotcrete/concrete mixture design and the equivalent mortar as each material maintains the same paste proportions at the aggregate-binder interface.

In this first step, the equivalent mortar method was used to select three candidate formulas presenting the most promising early-age strengths among many different mixture designs in a relatively quick and economical fashion when compared to shooting all of the candidate mixtures. The three candidate shotcrete mixtures selected include a variation of the earlier developed rapid strength-gain dry-mix shotcrete for mining applications (King RS-D2 Mining Shotcrete) but including an air-entraining admixture (CSA-AEA), and two shotcrete mixtures combining CSA cement-based binder with a redispersible polymer (CSA-Polymer A and CSA-Polymer B). During this first step, the three formulas were also adjusted to provide an initial set time of 20 minutes to guarantee a minimum finishing period.

For the second phase of the testing program, a full-scale shotcrete trial was conducted at King's facility (Sudbury, ON, Canada) using all three candidate shotcrete mixtures packaged in 66 lb (30 kg) bags (Fig. 1).

Shooting operations were conducted using an Aliva 246 dry-mix shotcrete machine (Fig. 2),

Fig. 1: Candidate shotcrete mixtures packaged in 66 lb (30 kg) bags

Fig. 3: Nozzleman shooting a test panel for later-age strengths and durability properties

Fig. 2: Aliva 246 dry-mix shotcrete machine

Fig. 4: Steel end-beam mold used for early-age strengths measurements

connected to a 2 in. (50 mm) hose with a hydromix nozzle introducing pressurized water to the material stream through a water ring located 10 ft (3 m) from the nozzle. Conventional shooting procedures described in ACI 506R-05, "Guide to Shotcrete," were followed for each dry-mix shotcrete formula tested (Fig. 3). All dry-mix shotcrete mixtures were shot using the "wettest stable consistency" as recommended by ACI 506R-05 for steel reinforcing bar encapsulation in repair applications.

Early-age compressive strengths were determined using the end-beam test method (using rectangular steel molds presented in Fig. 4), adapted from ASTM C116 (1990), whereas the initial set time was obtained using a hand-held penetrometer in accordance with the test method (ASTM C1117 [1994]).

Later-age compressive strengths and certain durability properties were determined using square test panels illustrated in Fig. 3. More precisely, the compressive strength at 7 and 28 days was obtained in accordance with ASTM C1604 (2012). The durability properties tested for each shotcrete mixture include the determination of the boiled water absorption and volume of permeable voids, rapid chloride permeability, air-void system analysis (CSA-AEA mixture only), and freezing-and-thawing resistance. The boiled absorption and volume of permeable voids was determined in accordance with ASTM C642 (2013). The rapid chloride permeability was determined in accordance with ASTM C1202 (2012). The freezing-and-thawing resistance was determined in accordance with ASTM C666/C666M (2008). The air-void system analysis was only determined on the CSA-AEA mixture in accordance with ASTM C457/C457M (2012). The two polymer-modified mixtures were air-cured only, whereas the CSA-AEA mixture was kept in wet curing conditions for 28 days prior to testing.

Results and Discussion

The early-age strengths and the initial set time measured on the three dry-mix shotcrete mixtures conformed to the results targeted during the preliminary tests using the equivalent mortar mixtures. As expected, all shotcrete mixtures started to set after 15 to 20 minutes and then rapidly developed compressive strength, reaching more than 3600 psi (24.8 MPa) after only 2 hours and reaching more than 7300 psi (50.3 MPa) after 28 days. The CSA-Polymer A shotcrete mixture reached a 28-day compressive strength in excess of 9000 psi (62 MPa). Early-

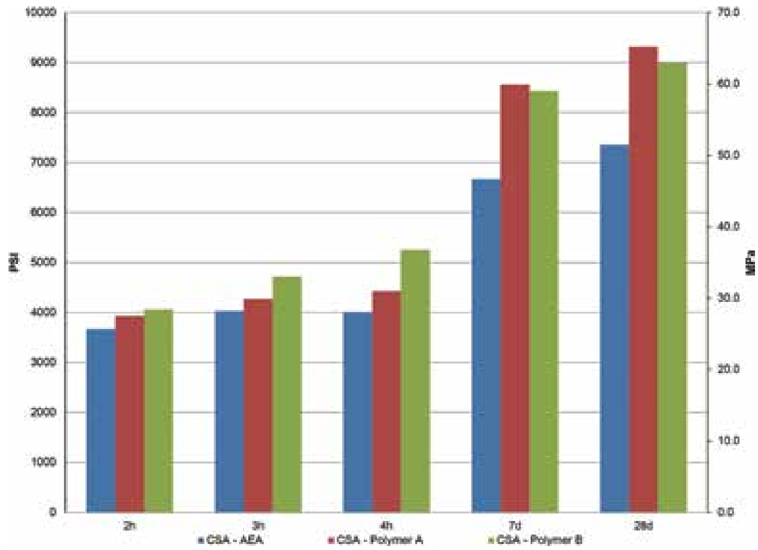

Fig. 5: Early- and later-age compressive strengths obtained with the candidate CSA cement-based dry-mix shotcrete mixtures

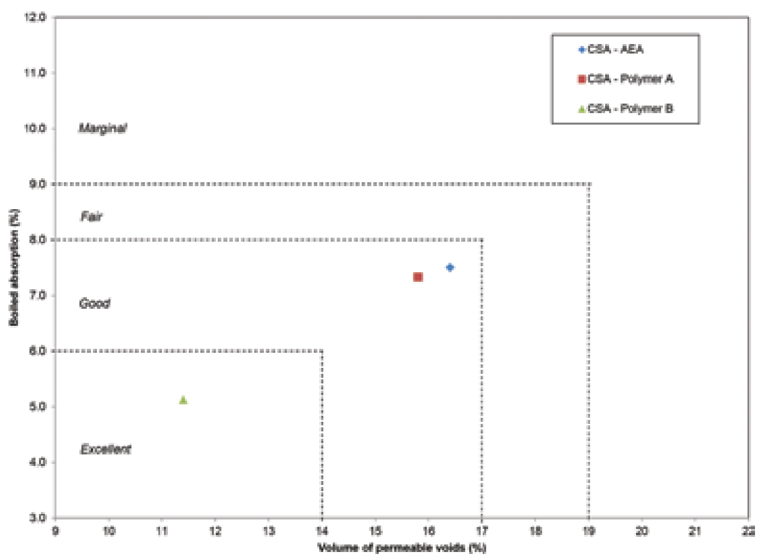

Fig. 6: ASTM C642 results obtained on the three CSA cement-based dry-mix shotcrete mixtures

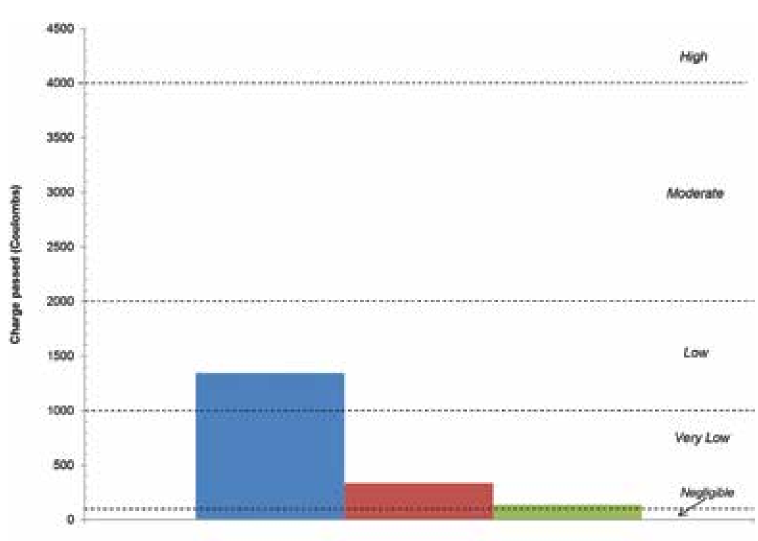

Fig. 7: RCPT (ASTM C1202) results and the associated chloride ion penetrability index obtained with the CSA cement-based dry-mix shotcrete mixtures

and later-age compressive strengths obtained for the three candidate mixtures are illustrated in Fig. 5.

Once the ultra-rapid strength development was confirmed for the three mixtures (refer to Fig. 5), the next step consisted of analyzing certain durability features and indicators.

The boiled water absorption and the volume of permeable voids were the first durability properties analyzed, as these tests are typically performed in the shotcrete industry to provide an indication of the quality of the in-place shotcrete. The absorption results obtained for the three CSA cement-based dry-mix shotcrete mixtures and the associated shotcrete quality indicators proposed in the literature and generally accepted in the industry (Austin and Robins [1995]) are presented in Fig. 6.

As shown in Fig. 6, in addition to very rapid strength development, the placed shotcrete quality was good to excellent (CSA-Polymer B mixture) for the mixtures shot according to the suggested indicators.

The rapid chloride penetration test (RCPT) results presented in Fig. 7 with the chloride ion penetrability index mentioned in ASTM C1202 also confirm a low to almost negligible (CSA-Polymer B mixture) chloride ion penetrability obtained with the rapid strength-gain dry-mix shotcrete mixtures tested.

Even if the absorption (ASTM C642) and the RCPT (ASTM C1202) tests present some limits to characterize shotcrete durability exclusively (Bolduc 2009; Bolduc and Jolin 2010), the excellent results obtained with the three mixtures under consideration demonstrate the high quality of the shotcrete produced with this alternative cementitious material.

In addition to the outstanding results presented previously in terms of strength development, material quality, and chloride ion penetrability, Table 1 confirms that the mixtures tested also possess excellent freezing-and-thawing resistance.

The air void system characteristics measured for the CSA-AEA mixture are presented in Table 2 and explain the excellent freezing-and-thawing resistance obtained with this mixture.

Based on the results obtained during this testing program, it is possible to produce a CSA cement-based dry-mix shotcrete that provides ultra-rapid compressive strength development, a good-to-excellent in-place material quality, a low- to almost-negligible chloride ion penetrability, and an excellent freezing-and-thawing resistance. Based on these very promising test results, the next step will consist of selecting one candidate shotcrete mixture to determine additional mechanical and durability properties required for materials used in repair applications.

Table 1: Freezing-and-thawing test (ASTM C666) results obtained after 300 cycles

Mixture	Durability factor (ASTM C666)
CSA-AEA	100%
CSA-Polymer A	100%
CSA-Polymer B	97%

Table 2: Air void system characteristics measured on CSA-AEA shotcrete mixture

Mixture	Air void system—ASTM C457, Procedure B	
	Hardened air content	Spacing factor
CSA-AEA	5.8%	214 µm

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The Durability of Shotcrete—Looking Back at Projects from 30 to 40 Years Ago

By Ted Sofis

Anyone who has ever had to remove old gunite from a bridge or an overpass knows how incredibly difficult it can be to tear out. When the durability of shotcrete was selected as the theme for this issue of *Shotcrete* magazine, the idea came up to look at some older projects. I mentioned that there were projects that we did 20 to 40 years ago that are still holding up well. With questions that engineers ask regarding shotcrete being a viable and accepted option for concrete repairs, nothing could be more relevant. So I decided to revisit a few of those projects and take a look at them today.

There aren't any secrets or shortcuts for achieving good results. Surface preparation is very important. Care has to be taken to remove the deteriorated concrete back to good, sound material. If you gun over bad concrete, you'll end

Fig. 1(a): Dry-process shotcrete repairs on 31st Street Bridge in Pittsburgh, PA, were done in 1973 over bottom two-thirds of this pier. Architectural details were maintained and shotcrete repairs remain in good condition 42 years after they were installed

Fig. 1(b): This pier on Pittsburgh side of Allegheny River required extensive repairs and shotcrete also remains in very good condition

Fig. 2(a): Arches and parapets of this single-arch bridge in Bridgeville, PA, were badly deteriorated before shotcrete repairs in 1977. Dowels and reinforcing bars were installed and dry-process shotcrete placed across arches on both sides of bridge

Fig. 2(b): Concrete on both sides of parapets under capstones were badly deteriorated. They were chipped out then replaced with dry-process shotcrete 38 years ago up with a poor result. Shotcrete is concrete—the only difference being the method of placement. The mesh and reinforcing steel has to be securely anchored and tied in place, so there is no movement or flex when the shotcrete is gunned. Otherwise it can pull from the surface, especially in overhead applications. Good workmanship is necessary, as are wetting down the receiving surface prior to gunning to get a saturated surface-dry (SSD) condition; using good gunning techniques; ensuring a good, consistent shotcrete mixture; allowing the shotcrete to get its initial set before starting to cut-down and finish the surface; and making sure the shotcrete is properly cured.

The 31st Street Bridge

The oldest of our projects that I revisited was the 31st Street Bridge in Pittsburgh, PA. The bridge spans the Allegheny River and Herr's Island, now referred to as Washington's Crossing. We were general contractor for the rehabilitation of the bridge and the work was done in 1973 and 1974. The project required steel repairs and extensive shotcrete repair work to the piers of the old bridge. The sand and cement was mixed on site with 3.5 ft^3 (0.1 m^3) of sand to one bag of cement. The mixture was measured in 1 ft^3 (0.03 m^3) wooden boxes as a quality-control measure. For the dry-process shotcrete placement, we used a Jetcreter, an early straight drop feed rotary gun. I remember the project well because I worked on the concrete tear-out crew during the removal stage and on the gunning crew during shotcrete placement. The most difficult part of the job involved cutting and finishing the architectural details on bridge piers. The bridge has undergone additional rehabilitation work in recent years for steel repairs and to replace the bridge deck, but the shotcrete installed on bridge piers 42 years ago remains intact and in good condition.

Bridgeville Arch Bridge

The second job, in Bridgeville, PA, involved dry-process shotcrete repairs to a concrete arch bridge that we rehabilitated in 1977. On both sides of the bridge, the concrete arch was badly deteriorated. We removed the concrete to a depth of 14 in. (350 mm) from the edge of the arch. Because of the depth of the repair, dowels were installed across the entire arch and reinforcing bars were installed. In addition to the arches, the concrete parapets were also badly deteriorated. So the deteriorated parapet concrete was removed, leaving the capstones in place. The shotcrete was then gunned in place and finished to grade. Considering the condition of the bridge when the repairs were done in 1977, it is remarkable that after 38 years, it has held up so well. When shotcrete is placed properly, it's as durable as any concrete repair.

Raccoon Dam and Spillway

We began rehabilitation of Raccoon Dam and Spillway at Raccoon State Park in Beaver County, PA, in 1983 and completed the shotcrete repairs in the second phase of the work in 1984. Prior to the shotcrete repairs, there had been problems with a polymer-modified patching mortar. The

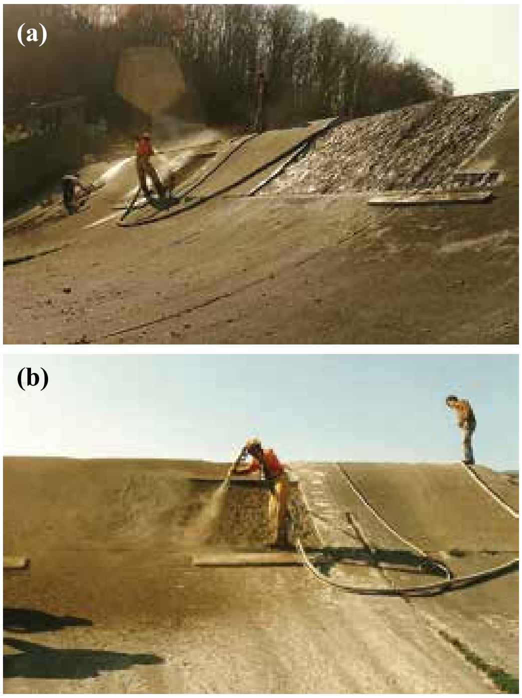

Fig. 3(a) and (b): (Before) Rehabilitation work on Raccoon Dam and Spillway (Raccoon State Park, PA) included removal and replacement of deteriorated concrete on large sections of spillway and across top of dam. These photos show dry-process shotcrete placed on upper sections of dam in autumn of 1984. Once placed, shotcrete was then cut down or rodded to grade before finishing

Fig. 4: (After) Shotcrete repairs to Raccoon Dam remain in good condition across crest of dam 31 years after shotcrete work was performed. Water flowing over crest of dam and spillway shows a relatively even flow despite the passage of years

perception of the owner's engineers was that polymer-modified patching mortar would give them a better job. After receiving our assurances, they allowed us to repair the crest of the dam with shotcrete. There were advantages to going with shotcrete. It was more efficient to transport the material through the gunning hose to the repair areas and we were able to gun the shotcrete to the full depth on sloped and vertical areas. In retrospect, it was the right decision. The shotcrete performed better than the polymer-modified patching mortar, and the shotcrete repairs have held up well over the years.

The Carnegie Museum Slope

In 1988, we began placing shotcrete to stabilize the slope behind the Carnegie Museum in Pittsburgh, PA. The museum needed additional parking and the only land available was over the hillside in Panther Hollow behind the museum building complex. Because of the valley, a parking garage was designed to sit below the back of the museum and the parking structure was incorporated into the hillside. We installed the dry-process shotcrete in sections with regular expansion joints and screeded the shotcrete to fairly regular grade, giving it a cut-down finish. With the passage of time, the shotcrete remains in very good condition.

When shotcrete is installed correctly it is as durable as any other method of concrete repair. As I stated earlier, there are no secrets for doing good work. It takes skilled personnel, an experienced gunning crew, and proper placement techniques. In my mind, the best test of durability is the test of time.

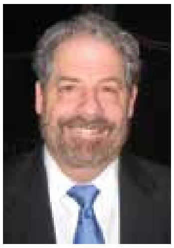

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Fig. 5(a) and (b): (Before) In 1988, dry-process shotcrete was placed for slope stabilization on hillside behind Carnegie Museum in Pittsburgh, PA. Recesses were left for precast concrete to support a parking garage that was later built over the hillside

Fig. 6 (a) and (b): (After) Dry-process shotcrete was used to stabilize slope for parking garage that was built into hillside behind Carnegie Museum in 1988. These photos of that work taken in February 2015 (27 years later) show that work remains in good condition. Sections of shotcrete slope can be seen on each level of parking garage


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Testing Air Content of Dry-Mix Shotcrete

By Lihe (John) Zhang

It has been well-established that the freezing-and-thawing resistance of concrete is improved by air entrainment. Air-entraining admixtures are often added to both wet- and dry-mix shotcrete primarily for durability considerations.[1-4] If shotcrete is required to have freezing-and-thawing resistance, a typical engineering specification will require:

- As-shot air content: 2.5 to 5.5%; and
- As-batched air content: 4 to 7%, 5 to 8%, or 6 to 9%, depending on exposure condition and maximum size of the aggregates.

It is a common practice to add air-entraining admixture into the wet-mix shotcrete because it is often batched as ready-mix concrete.

However, the question has been raised, from time to time, on whether dry-mix shotcrete should be air-entrained. About two decades ago, researchers and engineers originally developed the concept of air-entrained dry-mix shotcrete,[1-3] and its use is well-proven today.

It is widely recognized in the shotcrete industry that the air content of the as-batched shotcrete will drop during the shooting process. This results from high-velocity impact from the shotcrete process tending to "knock out" air from the mixture and thus reduce the air content of the in-place shotcrete. The as-shot air content in the in-place shotcrete is typically below 6% regardless of how high the as-batched air content was before shooting.[4] Testing for air content in the hardened shotcrete can be conducted by air voids analysis using the ASTM C457 test procedure. However, this test is time consuming and expensive and is thus not often used as a quality control (QC) test. This article provides project testing data for the as-shot air content for the dry-mix shotcrete.

An air meter is used to measure the air content of the plastic shotcrete or concrete. For the purposes of this article, air content measured at the point of discharge from the truck or at the end of the pump hose is referred to as-batched air content. Air content measured by shooting directly into the air meter base, or shot against a wall, into a wheelbarrow, or even into a basket, and then scraped out to fill the air meter, is called as-shot air content. Sometimes, the terminology of "air content at nozzle" is also used (erroneously) for the as-shot air content.

Air Content for Steel Fiber-Reinforced Dry-Mix Shotcrete

During a recent project in British Columbia, Canada, steel fiber-reinforced dry-mix shotcrete was applied for rock stabilization (Fig. 1).

The project specification required:

- 7-day compressive strength: at least 4400 psi (30 MPa);
- 28-day compressive strength: at least 5800 psi (40 MPa);
- Boiled absorption: maximum 8%;
- Volume of permeable voids: maximum 17%; and
- As-shot air content: 2.5 to 5.5%.

To meet the project specification and the durability requirement for freezing-and-thawing resistance, air-entraining admixture was added—in a powder format—into the pre-bagged materials of dry-mix steel fiber-reinforced shotcrete.

As-shot air content was tested to ASTM C231. The dry-mix steel fiber-reinforced shotcrete was shot on the ground in a pile. The shotcrete sample was taken from the piled shotcrete and tested for as-shot air content. The resultant as-shot air content is plotted in Fig. 2. Results show that the as-shot air content ranges from 2.7 to 5.0%. The average as-shot air content is 3.7%, with a coefficient of variation (COV) of 14.5%, and standard deviation of 0.5%.

Plot Air Content versus Compressive Strength

A typical air-entrained shotcrete dry-mix design will have an as-shot air content of approximately 3 to 5%. It is generally known that higher air content will generally reduce the compressive strength for cast-in-place (CIP) concrete.[5]

The correlation for as-shot air content versus 28-day compressive strength is plotted in Fig. 3 for the dry mix previously introduced in Fig. 2. As expected, there is no clear relationship between the two properties as opposed to CIP

Fig. 1: Steel fiber-reinforced dry-mix shotcrete

concrete. Indeed, the mechanisms behind the formation of an air bubble during placement of dry-mix shotcrete as well as those involved in rebound are all leading to a final in-place composition, where different factors (such as water-binder ratio, binder content, and air content) can have opposite effects on the resulting compressive strength. What is clear, however, is that even the highest air content measured allowed (4.8%) reached more than satisfactory compressive strength results.

Discussion

Why Do We Use Air Entrainment?

Entire papers could be written and research conducted as to the effect of different shotcrete-related parameters (including water content, velocity, and process) on the as-shot air content. However, the real question is whether or not we are able to generate a dense enough network of small air bubbles in the hardened shotcrete to protect it from freezing-and-thawing damage (that is, a small enough spacing factor). Unfortunately, the real answer comes from a test usually conducted only when qualifying a specific mixture design (ASTM C457, "Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete"); its relevance in QC is little because the test has to be conducted on hardened concrete/shotcrete samples, usually after more than 28 days. When an air-entraining admixture is incorporated in the mixture, the as-shot air content is an indirect measurement of the level of success we have in creating the dense small

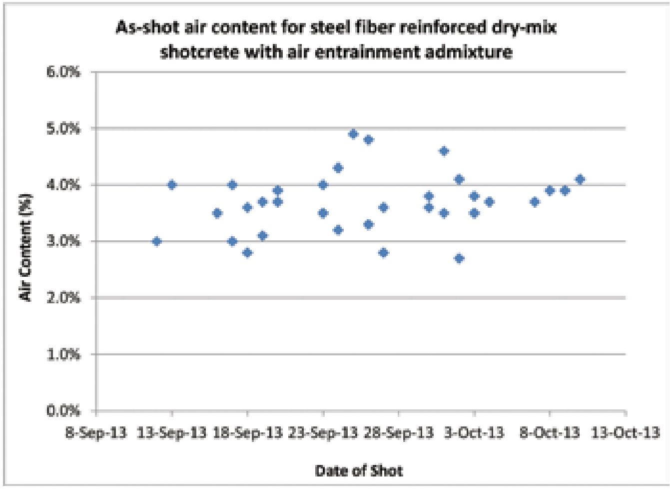

Fig. 2: As-shot air content for dry-mix steel fiber-reinforced shotcrete (air-entrained)

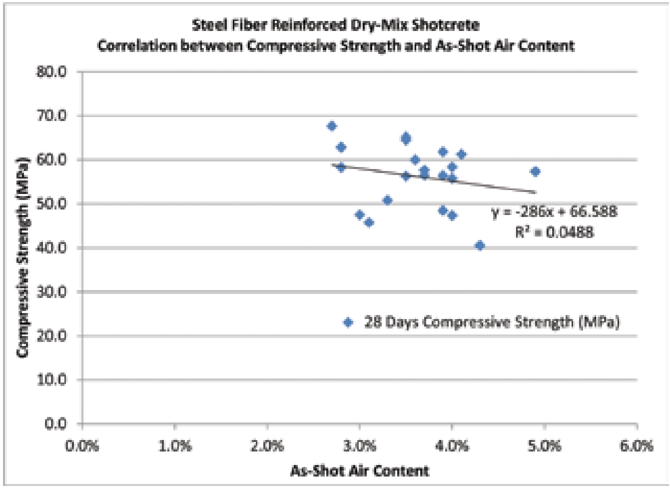

Fig. 3: Correlation between 28-day compressive strength and as-shot air content

bubble network; the as-shot air-content is therefore an excellent QC test.

Is It Possible To Test Air Content For Dry-Mix Shotcrete?

As water is added into the nozzle during the dry-mix process, the as-batched air content for dry-mix shotcrete cannot be tested. The as-shot air content for dry-mix shotcrete can be tested by shooting a pile to the ground or to the wall—samples can be taken from the as-shot shotcrete and tested in the air meter. Shooting directly into the air meter is not recommended, as that might damage the air meter.

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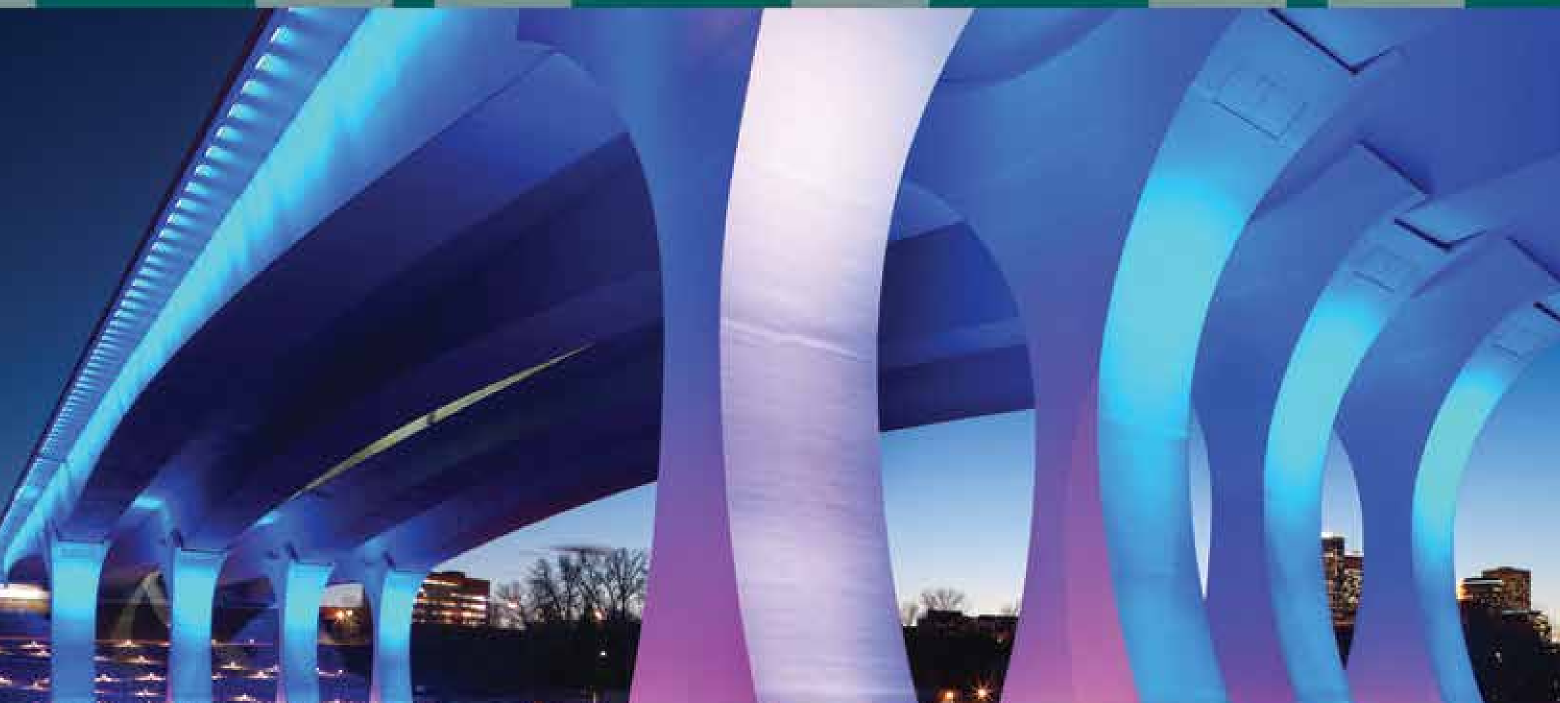

Effect of Pozzolanic-Based Rheology Control Agent as a Replacement for Silica Fume

on Wet-Mix Shotcrete Performance

By Ezgi Yurdakul and Klaus-Alexander Rieder

The purpose of this article is to present the performance evaluation of wet-mix shotcrete containing a pozzolanic-based rheology control (RC) agent as a replacement for silica fume (SF). The RC agent used in this study is a liquid-based product that contains nanoscaled colloidal silica particles with high pozzolanic reactivity. In this experimental program, five different mixtures were evaluated. One mixture was prepared as a reference mixture incorporating 5% SF by mass of cement. Four mixtures were prepared with RC agent at dosage rates of 0.67%, 0.80%, 1.30%, and 1.60% by mass of cement. Slump, rebound, early- and later-age strength, and the depth of water penetration were tested.

Test results showed that the SF mixture and mixtures containing RC agent provided similar slump and they were all very efficient in reducing rebound to the range of 5 to 6%. The addition of the RC agent increased the early-age strength compared to the SF mixture and provided similar strength at 7 and 28 days. The water penetration depth of the mixtures containing the RC agent was slightly lower than that of the SF mixture, as desired. The RC agent was more dosage-efficient, as it required much lower addition rate to provide equivalent performance to SF. Overall, it was found that for the investigated mixtures, the RC agent was a suitable alternative to SF in wet-mix shotcrete applications.

Introduction

SF is commonly added to shotcrete mixtures to improve strength and durability while reducing rebound. However, there are a number of limitations associated with its use. The first limitation is due to the variability of the purity of SiO_2, which results in a significant variation in the performance of SF in shotcrete. In addition, SF is a by-product of silicon and ferrosilicon production. Therefore, it contains impurities that may cause unwanted side effects, such as delays in setting time. Furthermore, the handling of SF may be challenging due to its powder form. As a result of these limitations, there is a need to replace SF with another substance that can provide similar performance while avoiding the challenges associated with the use of SF.

The pozzolanic-based RC agent is an alternative to SF, as it provides better (or at least equivalent) performance characteristics while avoiding the limitations mentioned previously. The RC agent used in this study is a liquid-based, fully stable product that contains uniformly distributed nanoscaled colloidal silica particles with a long shelf life. The specific surface of colloidal silica is higher than that of conventional SF and it consists of more than 99% SiO_2. Therefore, it has a very high purity and pozzolanic reactivity compared to SF.[1,2] When added to a wet-mix shotcrete, the RC agent significantly increases the cohesiveness while reducing bleeding and segregation.[3] Therefore, while also improving the sprayability and pumpability characteristics, it reduces rebound and increases maximum thickness of buildup. In addition, many researchers[4-8] stated that colloidal silica fills the space between particles of calcium silica hydrate (CSH) gel; hence, it acts as a filler to improve the microstructure. It also reacts with calcium hydroxide, thus increasing the amount of CSH gel, which in turn increases the densification of the matrix and improves durability. Furthermore, at sufficiently high addition rates, colloidal silica can accelerate the early-age hydration process of the shotcrete mixture, which reduces the time of setting and increases early-age strength compared to shotcrete mixtures containing SF.[9]

This article presents a comparative study to evaluate the performance of RC agents as alternatives to SF in wet-mix shotcrete applications.

The influence of different grades and dosage rates of RC agents on the fresh and hardened properties of shotcrete was evaluated.

Experimental Program

An extensive experimental test program was conducted at the Hagerbach Testing Gallery (VSH), which is an underground facility in Flums, Switzerland. A total of five mixtures were batched as shown in the following:

- Mixture 1—A reference mixture incorporating SF with the addition rate of 5% by mass of cement;
- Mixture 2—A mixture containing RC agent Grade 1 with the dosage rate of 0.67% by mass of cement;
- Mixture 3—A mixture containing RC agent Grade 1 with the dosage rate of 1.30% by mass of cement;
- Mixture 4—A mixture containing RC agent Grade 2 with the dosage rate of 0.80% by mass of cement; and
- Mixture 5—A mixture containing RC agent Grade 2 with the dosage rate of 1.60% by mass of cement.

RC agent Grade 1 had a smaller average particle size compared to RC agent Grade 2. Table 1 shows the mixture design used in this experimental program for the reference mixture selected to represent a generic mixture containing SF that is commonly used for shotcrete applications in Europe. It should be noted that as a result of replacing powder-based SF with liquid-based RC agents, the total cementitious materials content was 796 lb/yd^3 (472.5 kg/m^3) for the SF mixture and 758 lb/yd^3 (450 kg/m^3) for the mixtures incorporating the RC agents. The water-cementitious material ratio (*w*/*cm*) was kept constant at 0.435 for all mixtures.

Table 2 shows the test matrix used in this study. The presented results represent the average of two test results conducted on separate batches of the same mixture carried out on subsequent days.

Results and Discussion

Sprayability and Pumpability

Sprayability and pumpability are two key properties that reflect the distinctive process of shotcrete application and distinguish it from traditional cast-in-place concrete. Hence, it is important to understand the differences between these two parameters. Sprayability is the efficiency of a mixture at sticking to the applied surface (adhesion) and to itself (cohesion).[14] Pumpability is the stability and mobility of a mixture under pressure.[15] One of these two parameters is often compromised due to requiring conflicting properties. For pumpability, it is desired to have a mixture with low viscosity and high flowability (usually associated with high slump). However, for sprayability, a stiff and

Table 1: Mixture Design of SF Mixture

Mixture design	Quantity
Fine aggregate 0 to 0.04 in. (0 to 1 mm), lb/yd^3 (kg/m^3)	238 (141)
Fine aggregate 0.04 to 0.16 in. (1 to 4 mm), lb/yd^3 (kg/m^3)	1748 (1037)
Intermediate aggregate 0.16 to 0.32 in. (4 to 8 mm), lb/yd^3 (kg/m^3)	855 (507)
Cement (CEM I 42,5 N), lb/yd^3 (kg/m^3)	758 (450)
SF*, lb/yd^3 (kg/m^3)	38 (22.5)
High-range water-reducing admixture, % of total cementitious materials content	1.2
Hydration control, % of total cementitious materials content	0.3
Alkali-free accelerator, % of total cementitious materials content	6
w/*cm*	0.435

*SF was fully replaced with RC agents.

Table 2: Test Matrix

Tested property	Method	Age
Slump flow	EN 12350-5[10]	N/A
Early-age strength	EN 14488-2[11]	10 min, 30 min, 1 h, 3 h
Later-age strength	EN 12390-3[12]	7 d, 28 d
Water penetration resistance	EN 12390-8[13]	28 d

sticky mixture with low slump and high cohesiveness is desired to minimize rebound and increase buildup thickness.[15]

Currently, there are no standardized test methods that can measure sprayability and pumpability. Therefore, it is a common practice to assess consistency, viscosity, rebound, and buildup thickness to evaluate the sprayability and pumpability of a particular mixture. In this study, slump flow was tested to evaluate the flowability as an indicator of pumpability, and rebound was tested to evaluate the sprayability characteristics of the tested mixtures.

Figure 1 shows the effect of two RC agents and SF mixtures on slump flow, which was targeted as 20 ± 1.25 in. (500 ± 30 mm). All the tested mixtures were within the acceptable variation limits of the target slump, and they performed similar to each other regardless of their mixture constituents. For a given grade of RC agent, increasing the dosage rate slightly reduced slump due to the increased particle packing, which decreased the volume between them as well as the free water. However, because the selected dosage rates for the two RC agents were within the manufacturer's recommended limits, the impact on the water demand was negligible.

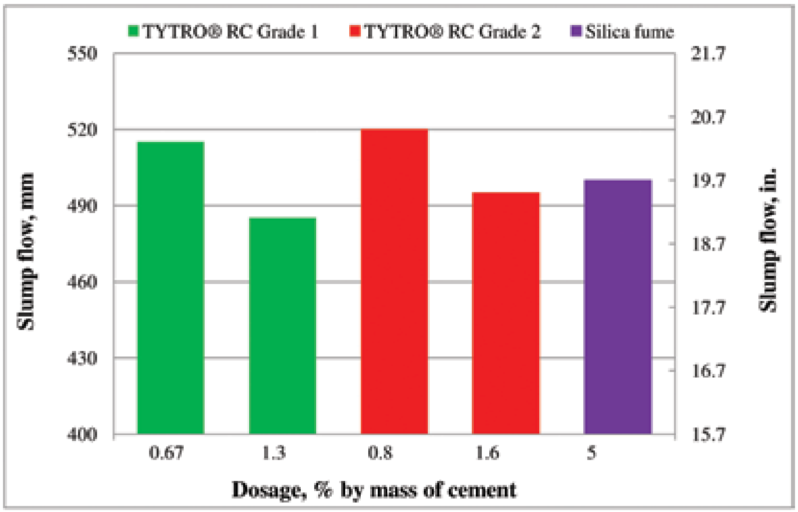

Fig. 1: Effect of two RC agents and SF on slump flow

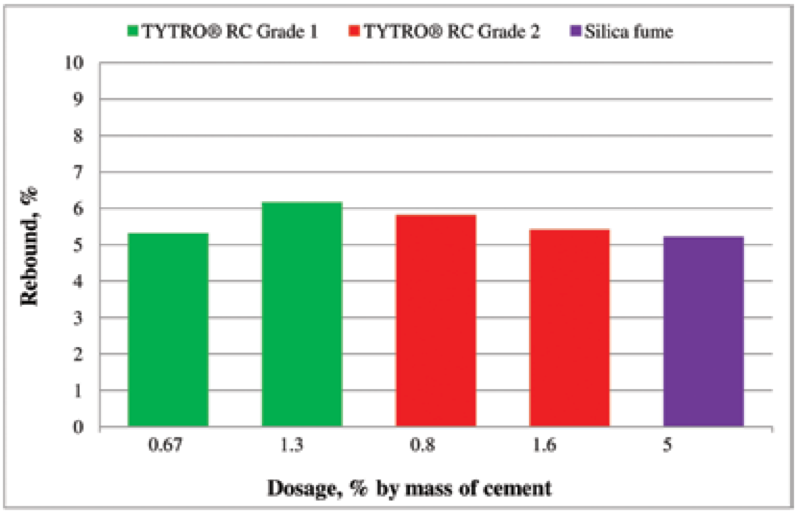

Fig. 2: Effect of RC agent and SF on rebound

It should be noted that slump flow only indicates consistency (ease of flow) and does not evaluate cohesiveness (tendency to bleed and segregate). It is especially important for shotcrete mixtures to have high cohesiveness, as they are less prone to segregation under pressure. Having a mixture with high cohesiveness and stickiness is also desired to maximize thickness buildup and minimize rebound. Due to the smaller particle size associated with higher specific surface area of the RC agents, they work as nucleation sites for the precipitation of CSH gel, and have stronger Van der Waals and electrostatic ionic forces between particles.[8] Considering that the main source of cohesion in cement paste is the CSH gel,[16] it is expected for RC agents to increase cohesion due to a) its impact on accelerating and forming additional CSH gels; and b) its reactant surface particles exhibiting stronger tendency for adsorption of ions and increasing the surface adhesion between adjacent particles and to other materials.

Rebound

The mixture was sprayed with a pump rate of 7.85 yd^3/h (6 m^3/h) with a pump pressure ranging between 800 and 870 psi (55 and 60 bar) on a vertical concrete wall of 6.6 x 6.6 ft (2 x 2 m) with a thickness of about 4 in. (100 mm). TYTRO® SA alkali-free set accelerator was added at an amount of 6% of the total cementitious materials content directly at the nozzle. After finishing the spraying process, the amount of concrete on the concrete slab and the rebound were measured with a balance.

Rebound loss is affected by many factors, such as the position of the application, distance and angle of the nozzle from the sprayed location, skill and expertise of the nozzleman, air pressure, impact velocity, thickness of layer, amount of reinforcement, and mixture design (for example, cementitious materials content, water and air content, size and gradation of aggregates, and the presence and dosage rate of admixtures). According to the ACI 506 guideline,[17] for vertical walls, the approximate range of rebound loss is 10 to 30%. In many field applications, it is common to obtain higher than 15% rebound. According to Fig. 2, mixtures containing SF and RC agent were efficient in reducing rebound to as low as 5 to 6%. Based on the aforementioned information, it is a significant improvement to obtain a rebound loss at such low percentages for vertical walls. The improvement on rebound loss is related to the mixture design of the reference mixture. The reference mixture containing 5% SF was already optimized, and thus had the optimum combined aggregate gradation along with the cementitious materials content and *w/cm*. Because the rebound loss of the baseline mixture was already considered to be very low, the impact of the RC agents in achieving similar low rebound loss at much lower dosage rates was a significant improvement. However, case studies have shown that when the performance of the RC agents on rebound is compared with those of mixtures containing portland cement only, or mixtures containing SF with rebound losses higher than the one obtained in this study, the decrease in rebound with mixtures containing RC agents is more dramatic.

Early Strength Development

The first few hours are critical in mining/tunneling operations for re-entry; therefore, it is desirable for shotcrete mixtures to have a high strength-development rate. Figure 3 shows the comparison of the early-age strength between the SF mixture and mixtures containing the RC agents. From the initial testing conducted at 10 minutes after spraying until 3 hours after spraying, mixtures containing the RC agents outperformed the mixture containing SF. This is likely due to the specific surface area difference between these two materials because the rate of pozzolanic reaction is proportional to the amount of surface area available for reaction.[1] In addition, colloidal silica in the RC agents also reacts with the calcium hydroxide released by the cement hydration, forming additional CSH gel, and also accelerates the primary CSH gel formation, which is responsible for strength development. Distinct from the RC agents, SF only reacts to form CSH gels and does not contribute to the acceleration of CSH formation at typically used dosage rates.

Later-Age Strength

Strength at 28 days is commonly specified in project specifications that are often used for quality control of the structure. Figure 4 shows the effect of SF mixture and mixtures containing RC agent on 7- and 28-day cube strength. The two tested RC agents provided similar strength to SF at 7 and 28 days. Generally, admixtures accelerating the strength development rate at early ages may cause an ultimate strength reduction.

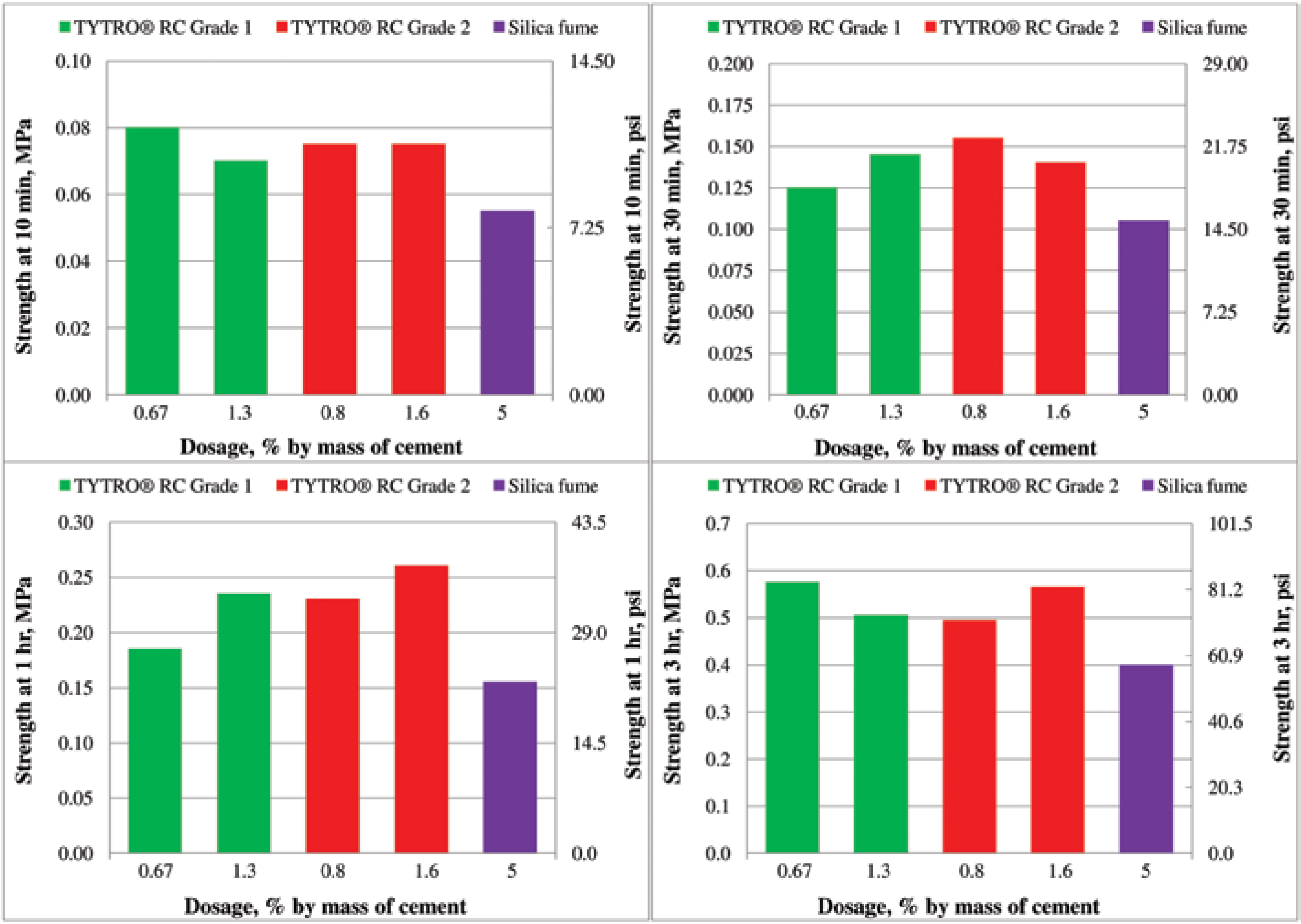

Fig. 3: Effect of RC agents and SF on early strength development

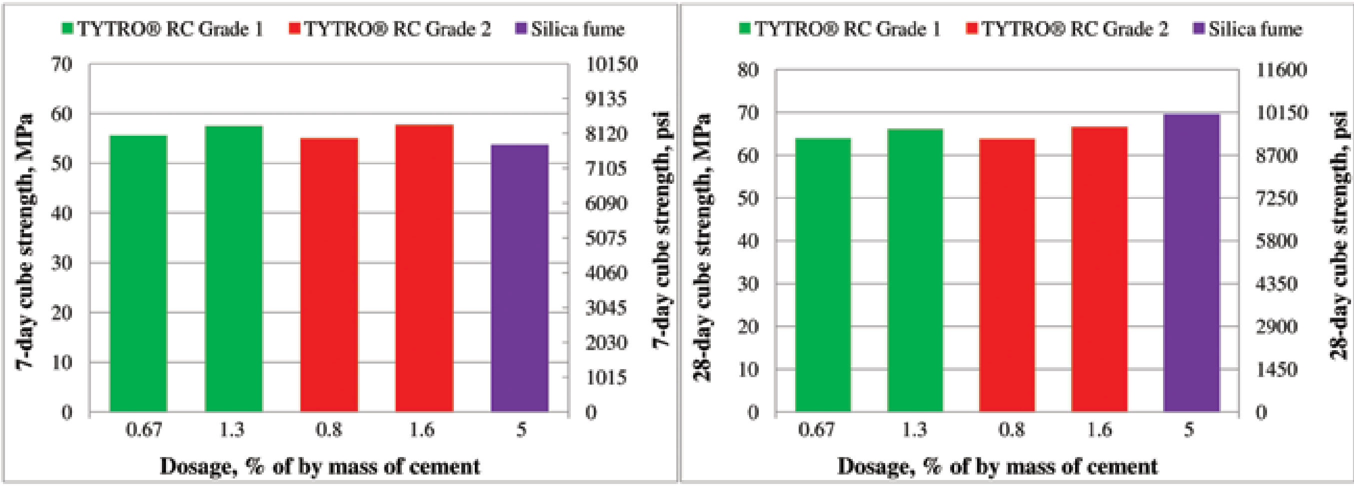

Fig. 4: Effect of RC agents and SF on the strength at 7 and 28 days

However, these results show that due to their pozzolanic nature, the RC agents reacted faster than the SF at early ages, and still achieved comparable 28-day strength. In addition, the impact of the selected dosages and grades of the RC agents on 28-day strength was marginal.

Durability

Durability plays a key role in determining the life span of structures, and it is often assessed by evaluating the permeability, which governs the rate of flow of a fluid (or gas) into a porous solid. If concrete or shotcrete mixtures have high permeability, deleterious substances can migrate into the structure, especially if they are exposed to chemical attack or freezing-and-thawing cycles. To evaluate the effect of the two RC agents and SF on the permeability, water penetration tests were carried out at 28 days.

Figure 5 shows that the water penetration depths of the mixtures containing the two RC agents were slightly lower than those of the SF mixture, as desired. This is most likely due to the following two potential reasons. The paste content of the mixtures containing the RC agents was lower than that of the SF mixture (as a result of replacing the powder-based SF with the liquid-based RC agents). In general, aggregates are likely to be denser than the cement paste and have a lower permeability than the cement paste, so mixtures with lower paste content tend to have lower permeability. On the other hand, the colloidal silica contained in the RC agents decreases the permeability by increasing the density of the interfacial transition zone (the weakest phase in concrete) as a result of the combination of its filler effect and high pozzolanic reactivity. SF also has pozzolanic properties, but because the reactivity and the surface area of the RC agents are higher than those of SF, the degree of their contribution to the permeability/durability will be influenced accordingly.

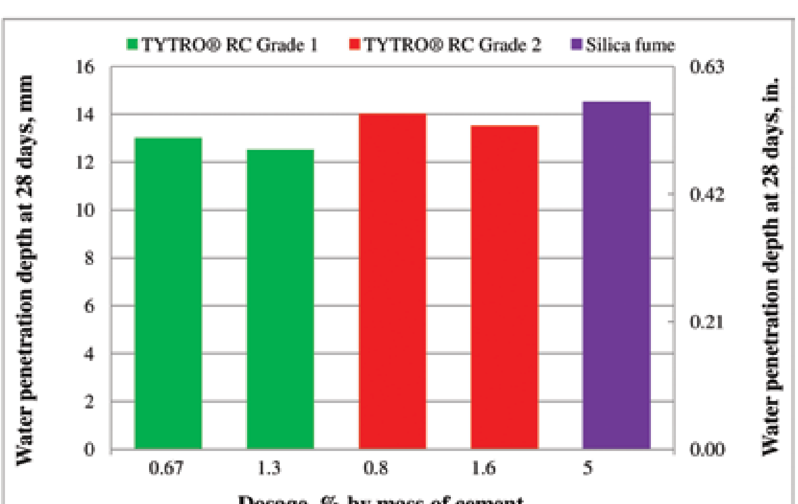

Fig. 5: Effect of the RC agents and SF on the water penetration depth at 28 days

Conclusions

The following conclusions were drawn based on the test results obtained from the investigated shotcrete mixtures:

- The SF mixture and mixtures containing the RC agents provided similar slump and were all very efficient in reducing the rebound loss to a range of 5 to 6%;
- The addition of the RC agents increased the early-age strength compared to the SF mixture, and provided similar compressive strength at 7 and 28 days;
- The water penetration depth of the mixtures containing the RC agents was slightly lower than that of the SF mixture, as desired;
- The impact of the selected dosages and grades of the RC agent on the performance was minor for the investigated non-fiber-reinforced shotcrete mixtures;
- The RC agents were more dosage-efficient than SF, as they required a much lower dosage rate to provide equivalent performance; and

- Overall, the RC agents tested were found to be efficient components to enhance the properties of wet-mix shotcrete.

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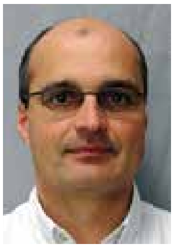

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Sustainable Transportation Retaining Walls

Denver RTD West Corridor

By Warren Harrison

Fig. 1(a): Jefferson County Government station under construction. Full depth—33 feet (10 m)—supporting adjacent highway with permanent soil nails and shotcrete (Photo courtesy of Harry Olsson)

Fig. 1(b): Wall under construction showing carved shotcrete facing, which is also structural member of final permanent wall structure (Photo courtesy of Harry Olsson)

Sustainability, to me, is the stingy use of scarce resources (money) and the inherent long life of a well-designed structure. This thereby minimizes capital expenditures and increases the economic life of the facility, minimizing maintenance costs.

The use in the last 40 years of geotechnical designed structures is a good example of sustainability. The use of the inherent strength of in-place rock and soil to build a structure is an excellent example of sustainable construction practices.

The original as-bid design of the new light rail station at the Jefferson County Justice Center had a 33 ft (10 m) high retaining wall supported with a double row of large-diameter drilled concrete caissons. The wall had to support the nearby US Highway 6 and also contend with drainage from snow removal on the highway.

As an alternate design, with the help of Bill Zietlow, we proposed a soil nail wall solution with a carved shotcrete facing. To ensure that the design was feasible, we invested in three additional soil borings and performed triaxial testing to determine our design assumptions.

The idea of a carved wall came from a site visit during the ACI Convention in San Diego, CA, to the California Coastal Line Station near San Diego. The carved shotcrete was very impressive and made a very inviting station atmosphere.

The final station walls consisted of approximately 22,000 ft^2 (2040 m^2) of soil nail and shotcrete walls and 12,000 ft^2 (1110 m^2) of carved shotcrete walls, which were shot and finished by Boulderscape of California. The non-carved shotcrete was in the tunnel section of the station.

The carving and architectural effect was the main reason the design change was approved

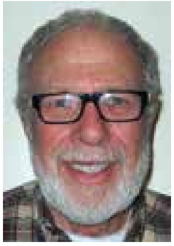
Fig. 1(c): Extent of shotcrete station wall before backfill of drainage and rail bedding (Photo courtesy of Harry Olsson)

Fig. 2(b): Light rail station east section retaining wall showing support for adjacent bridge abutment

Fig. 2(a): Jefferson County Government/Golden light rail station in operation, showing adjacent US Highway 6

Fig. 2(c): Light rail station showing shotcrete and soil nail support for tunnel out of station

by the local boards of Jefferson County and Golden, CO. The foresight of the general contractor, Transit Construction Group (DTCG)—a joint venture combining Herzog Contracting Corp. of St. Joseph, MO; Stacy Witbeck Inc. of Alameda, CA; and RTD, the owner—made this a great solution for the project. This innovative technique in building retaining walls also earned this project the "Award of Excellence" in 2011 from the Rocky Mountain Chapter – ACI, awarded at the chapter's 43rd Annual Concrete Awards Program.



***Warren Harrison**, PE, is the President of WLH Construction Company in Denver, CO, specializing in shotcrete, soil nailing, grouting, and concrete repair. He is currently serving as a member of ACI Committee 506, Shotcrete, and is a past Board member of ASA. A graduate of the Colorado School of Mines with an MBA from the University of Colorado at Denver, Harrison has worked on projects from Kodiak, AK, to Tiberius, Israel, and many places in between.*

Layers in New York City Overhead Tunnels

By Frank E. Townsend III

The New York City Transit (NYCT) Metropolitan Transportation Authority Capital Construction (MTACC) has several large-scale projects throughout New York, including one major program: the East Side Access project. On many of these projects, Superior Gunite has been subcontracted to shotcrete the arch placements in lieu of cast-in-place concrete due to construction form costs and time savings. These arches range from 12 to 30 in. (300 to 760 mm) thick, encasing two layers of No. 9 (No. 29M) reinforcement at 6 in. (150 mm) on-center spacing. The general contractor, MICHELS Corporation, subcontracted Superior to shotcrete this work, and due to the thickness and complexity of reinforcement, we chose to place the shotcrete in layers. The NYCT MTACC requested that Superior Gunite prove our placement methods for these overhead placements in a mockup, where the structural performance could be verified by bond testing. The pulloff test was conducted using ASTM C1583/C1583M-13, "Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)." The criteria we had to meet in the bond test was 100 psi (0.69 MPa) or greater.

We took this opportunity to test two different surface preparations and configurations for lay-

Fig. 1(a): Bond test panel, unreinforced

Fig. 2(a): Nozzle-finished panel

Fig. 1(b): Bond test panel after two layers were shot

Fig. 2(b): Scratch/etched finished panel, unreinforced ered, overhead shotcrete. Two boxes were made with a nozzle finish and the other two boxes were scratched, leaving an etched surface finish. No reinforcement was installed for any of the layers and all layers were prepared with a water hose cleaning between layers. Each layer had a minimum cure time of 24 hours prior to the placement of the subsequent layer. Two layer configurations were also tested on each of the finishes mentioned previously: for one set, three layers were placed, each with 4 in. (100 mm) lifts; and the second set of boxes were placed in two layers, each with 6 in. (150 mm) lifts.

The boxes were 3 x 3 ft (0.9 x 0.9 m) plywood with flared ends. All of the panels were identified and marked accordingly. Three 4 in. (100 mm) cores in each box were taken 0.75 in. (19 mm) beyond the layer interface into the second layer from the four panels. Surface preparation was done by the lab, Tectonic, the day prior to the bond test by cleaning the surface and using an epoxy adhesive (J-B Weld, one-half tube of each per puck) to adhere a steel puck to the concrete.

Fig. 3(a): Epoxy adhesive


Fig. 3(b): Preparing each puck

The test apparatus was calibrated prior to the test and nine tests were performed at 11 days from the surface to the next layer down and three tests were performed at the 28-day mark from the intermediate layer to third layer. The test involved pulling on the steel plug (attached to the core face) using a hydraulic jack. The test equipment setup included: a hydraulic jack (cylinder and piston with a center hole); a manually operated hydraulic pump; hydraulic fluid pressure gauge; valve; threaded rods/nuts; shackle; eyebolt; and steel U-frame.

Using the hand-operated hydraulic pump, the hydraulic jack was actuated and a tensile load applied on the test area. The load applied by the jack on the specimen is related to the hydraulic fluid pressure that is indicated by the pressure gauge included in the setup. Calibration charts of the hydraulic pressure to load relationship for the combination of jack and gauge were previously prepared by the testing lab during calibration of the jack.

The load applied on the test area was obtained by reading from the calibration chart corresponding to the pressure shown by the pressure gauge. The tensile load was gradually applied in four increments up to the required strength of 100 psi (0.69 MPa) and then load was gradually increased to failure. The maximum load applied and type of fracture was recorded. Test results (in psi) are shown in Table 1.

The test data shows that the specimens where the surfaces between layers are scratched pass the bond test (Box 1 and 2). In fact, the failure stress was not at the interface but in the glue that adhered the steel puck to the concrete. In our testing, the nozzle finish alone did not pass an 11-day bond strength test. However, the testing lab also noted that the unevenness of the rough, nozzle-finished


Fig. 3(c): Adhered pucks


Fig. 4: Pressure being applied via hand jack

Table 1: 11-Day Tensile Strength of Bond Test (First test: MICHELS Corporation)

	Specimen	Result	Failure	Average
Three layers, prep scratch finish 4 in. (100 mm) each lift	1A	132	Glue plane	164
	1B	185	Glue plane	
	1C	174	Glue plane	
Two layers, prep scratch finish 6 in. (150 mm) each lift	2A	95	Glue plane	141
	2B	179	Glue plane	
	2C	148	Glue plane	
Three lifts, prep nozzle finish 4 in. (100 mm) each lift	3A	95	Glue plane	76
	3B	47	At layer interface	
	3C	84	At layer interface	
Two lifts, prep nozzle finish 6 in. (150 mm) each lift	4A	99	Glue plane	58
	4B	32	At layer interface	
	4C	42	Glue plane	
Between second and third layer				
Three layers, prep scratch finish 4 in. (100 mm) each lift	1D	248	Glue plane	200
	1E	215	Glue plane	
	1F	138	Glue plane	

surface caused uneven stress with the test U-frame that may have contributed to the lower tensile bond strength. The nozzle finish may have better bond in other situations. The procedures followed and the criteria met the guidelines of ACI 506R-05, "Guide to Shotcrete." With these full-scale tests, we have proven that layers produce structurally monolithic sections when the surface is scratched, and we have proposed to do this on these MTACC projects.

Fig. 5(a): Picture of glue plane failure

Fig. 5(b): Picture of layer interface failure

Following the pull test, Superior performed the mockup in layers. With all overhead work being performed in layers, each layer was prepared and shot with a 2- to 14-day time lapse between lifts.

After the mockup was performed, cuts were made through different locations. As you can see, the encapsulation of the reinforcing bars and water stop was excellent. Layering was not evident, and with the pull test data, this allowed Superior Gunite to proceed with the work.

A follow-up test was performed for the East Side Access MTA project CM006 with another general contractor (GC), Frontier Kemper. The same procedure was followed, but only a scratch finish was prepared in the two boxes. More of the J-B Weld adhesive for gluing on the steel pucks was used on this second test to try to obtain better results. Although the additional glue raised the test results, the failures were still in the glue and not between the shotcreted layers. Table 2 shows the test results (in psi).

A larger mockup was performed for this project and cuts were made through the shotcreted arch to evaluate the encapsulation.

In all the tests with a roughened, scratched surface preparation between layers, we were never able to break the bond between layers with the test because all the tests failed at the glue adhering the steel puck to the concrete surface. Conversely, our tests showed that shooting a subsequent layer on top of an unfinished, nozzle-finished surface

Fig. 6(a): Mockup

Fig. 6(b): Arch mockup in layers

Fig. 6(c): Wall mockup in single pass

Fig. 7(a): Cut through the single pass wall mockup in layers

Fig. 7(b): Good encapsulation

Table 2: 11-Day Tensile Strength of Bond Test (Second test: Frontier Kemper)

	Specimen	Result	Failure	Average
First layer				
Three layers, prep scratch finish 4 in. (100 mm) each lift	1A	150	Glue plane	216
	2A	264	Glue plane	
	2C	233	Glue plane	
Second layer				
Three layers, prep scratch finish 4 in. (100 mm) each lift	1B	267	Glue plane	263
	1C	244	Glue plane	
	2B	278	Glue plane	

Fig. 8(a): Arch cut, single pass

Fig. 8(b): Arch cut, two layers

Fig. 8(c): Cut mockup

NYCT MTACC East Side Access Project
Project Name CM005 and CM006
Project Location Manhattan, NY
Shotcrete Contractor Superior Gunite
General Contractors MICHELS Corporation and Frontier Kemper
Architect/Engineer New York Metropolitan Transportation Authority Capital Construction (MTACC)
Material Suppliers/Manufacturers Ferrara Brothers Building Material and Teccrete
Lab Tectonic

produced much lower test results. Although the tests were not overly complicated, we proved to the general contractors and the MTACC that shotcrete sections shot out in layers with proper surface preparation between layers produces concrete sections that structurally act monolithically.

Frank E. Townsend III *is the East Coast Region Manager for Superior Gunite. He is a civil engineering graduate of Worcester Polytechnic Institute, Worcester, MA, and received his master's degree from the University of Missouri, Columbia, MO. Townsend comes from the U.S. Army Corps of Engineers and has been running Superior's East Coast operations (predominantly New York, New Jersey, Connecticut, and Boston, MA) for 3 years now. Townsend is an active member of ASA and currently serves on the ASA Board of Directors.*

Sewer Rehabilitation Using Shotcrete

By Randle Emmrich

For more than 70 years, century-old brick, clay, and tile sewers have been rehabilitated with shotcrete. Most of these sewer systems are found in the United States' major cities where the infrastructure was put into place by hand between 80 and 100 years ago. It is impressive to view the craftsmanship that went into the construction of these miles of pipe. It is just as impressive to witness how well they have held up over time. Unfortunately, most of these systems are reaching or exceeding their life expectancy and are in need of rehabilitation or repair. Enter shotcrete.

All of these sewer systems, whether they are sanitary, storm, or combined, are located under roadways, buildings, and other structures—not exactly convenient or cost-effective for tearing up and rebuilding. Thankfully, these structures do not need to be closed, dug up, or altered for a shotcrete liner to be installed. In fact, most of the time the public is unaware that work is being performed underneath them.

Shotcrete equipment can be set to the side of the road near the manhole used for accessing the pipe. Water in the pipe can be diverted, bypassed, or handled within the sewer line. If the sewer is in structural disrepair, reinforcing steel can be installed and a 4 to 6 in. (100 to 150 mm) shotcrete lining can be constructed (in essence, a new concrete pipe is built inside the existing one using the old sewer as a back-form). If the sewer is structurally sound but is experiencing water leaks, soil infiltration, or loose clay/bricks/tiles, a 3 in. (75 mm) thick polypropylene fiber-reinforced shotcrete lining is sufficient, along with a grouting program to fill any voids outside of the sewer. A shotcrete lining can add 50 years of new life to a sewer.

Most of these old systems are large in diameter (ranging from 4 to 21 ft [1.2 to 6.4 m]) and can be horseshoe, elliptical, or round in shape. Usually the flow in the sewer never reaches full capacity; therefore, a 3 to 6 in. (75 to 150 mm) lining does not impact the sewer's capability of handling peak flows. In addition, the hydraulic capacity can be increased due to smoothing of the lining using shotcrete. Shotcrete is especially beneficial in that it is versatile and can be placed over abnormalities and around tight turns in the system, unlike other rehabilitation liners. In addition, manholes do not need to be enlarged or altered as long as a person is able to gain access to the sewer line. Other rehabilitation liners can require 4 ft (1.2 m) diameter manholes to place the new liner.

Coastal Gunite Construction Company completed the rehabilitation of a large-diameter,

Fig. 1: Existing 100-year-old brick combined sewer

Fig. 2: Installed galvanized welded wire reinforcement (2 x 2 in. [50 x 50 mm], 12 gauge)

brick, egg-shaped combined sewer in late 2013 in Muncie, IN, for the Muncie Sanitary District (MSD). The project was advertised as a cured-in-place pipe (CIPP), modified polymer liner, or shotcrete rehabilitation job. When the bid results were announced, shotcrete was by far the most economically sound option. The sewer is 100 years old (Fig. 1) and the 6500 ft (2000 m) section that was rehabilitated ranged in size from 48 to 56 x 92 in. (1.2 to 1.4 x 2.3 m). There were a few 24 x 36 in. (0.6 x 0.9 m) sections that were subcontracted to Insituform Technologies (a CIPP contractor). The project was designed by GRW Engineers, located in Indianapolis, IN.

This particular sewer rehabilitation project consisted of installing a 3 in. (75 mm) thick welded wire fabric reinforced shotcrete lining around the entire circumference of the sewer line. The sewer was fairly clean of debris, but some root and loose brick removal was required prior to the installation of the wire. The installed welded wire reinforcement consisted of 2 x 2 in. (50 x 50 mm), 12/12 gauge galvanized wire conforming to ASTM A185 (Fig. 2). The wire was placed 1 in. (25 mm) from the existing brick substrate with 1/4 x 3 in. (6 x 75 mm) hook anchor bolts spaced 24 in. (0.6 m) in each direction (Fig. 3).

Coastal Gunite opted to use dry-mix shotcrete batched on-site. The compressive strength requirement was 5000 psi (35 MPa) at 28 days, and was easily accomplished with the site-batched mixture. Once the reinforcement was installed, the shotcrete was placed in two lifts (Fig. 4). To ensure that the required shotcrete thickness was achieved, measuring pins were placed at 5 ft (1.5 m) centers in each direction (Fig. 5). The final finish of the shotcrete was a brush finish parallel to the direction of the flow in the sewer (Fig. 6). Coastal Gunite mobilized in June 2013 and all shotcrete lining was

Fig. 3: Close-up of wire reinforcement lap and brick substrate

Fig. 5: Measuring pin installed to ensure correct thickness of shotcrete

Fig. 4: First lift of dry-mix shotcrete

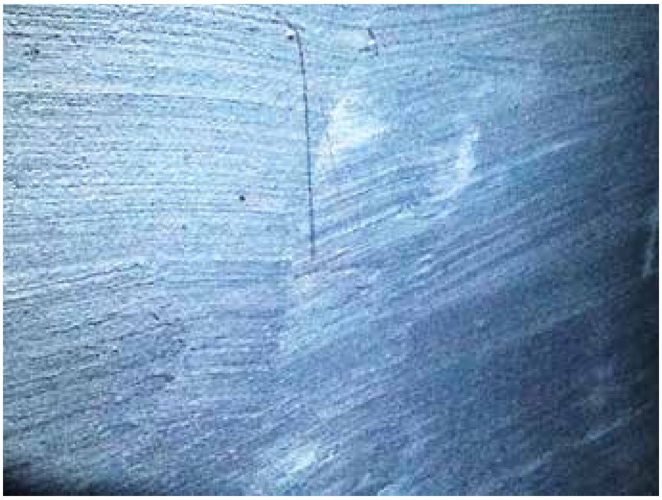


Fig. 6: Brush finish parallel to the direction of the flow

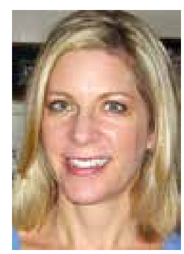
completed by December 2013 before cold and wet weather became an issue.

One complication encountered throughout the project was the control of water—not the flow inside the sewer pipe itself, but the seepage of groundwater through the invert. Due to the age of the sewer and the brick composition, the grout between the bricks was deteriorated (or missing!) in many sections, allowing a steady stream of groundwater to infiltrate the system. This was not discovered until a complete bypass system was established to handle the internal flow of water.

Because shotcrete cannot be successfully installed on top of running water, Coastal Gunite had to determine how to prevent/control the external infiltration of water into the pipe system's invert. Solutions considered included external grouting, wellpointing, and diversion. In this instance, the chosen solution was a wicking product to divert the flow away from the shotcrete during placement.

MSD was pleased with the end result and satisfied that they obtained a liner that would last for many years to come (Fig. 7). They were also happy that the roadways were left undisturbed, the traveling public was detoured in only a few areas, and the aboveground site conditions were restored to conditions better than they were prior to the start of the project. The largest benefit to MSD was the savings they gained by choosing shotcrete over another lining system. Coastal Gunite was happy to learn that the city of Muncie, IN, will consider the use of shotcrete to rehabilitate more of their aging sewers in the future and tell other municipalities about their positive experience.

Fig. 7: Finished shotcrete lining



***Randle Emmrich** is Vice President and Project Manager for Coastal Gunite Construction Co., Bradenton, FL. She received her BS in civil engineering from Bucknell University in May 1996. In her 18 years in the shotcrete business, she has overseen many projects, including the rehabilitation of bridges, piers, manholes, aqueducts, and sewers. Her projects have served various clients, including the U.S. Army Corps of Engineers, ESSO Inter-America, Maryland Transportation Authority, Virginia Department of Transportation, the City of Atlanta, and the City of Indianapolis. Emmrich is a member of ASCE; Chair of ACI Committee C660, Shotcrete Nozzleman Certification; and a member of ACI Committee 506, Shotcreting.*

Evaluating Ready Mix Suppliers

By Mark Bradford

Oscar Duckworth has covered the keys of the equipment necessary for successful wet-mix shotcrete in the past few "Nozzleman Knowledge" articles. This article discusses the importance of the material supplier in the equation.

One of the most critical pieces to what we do, as wet-mix shotcrete contractors and nozzlemen, is monitor the quality and consistency of the concrete that we are placing. As we all know, shotcrete is a method of placing concrete. The ingredients in concrete vary in dosages, but with the right mixture design, the concrete should provide good quality with long-lasting results.

Let us discuss a key variable in the equation that is often overlooked: the ready mix supplier. The supplier consists of the dispatcher, the batch plant, the delivery truck, and the truck driver.

A good concrete supplier can help make your day of shotcreting very smooth. A bad supplier can make your day or job a nightmare.

To begin with, you need to determine where the job is located. Then determine which suppliers service that particular area. Some areas are serviced by several suppliers; some areas are only serviced by one or two. In conjunction with determining who services that area, you should ask around to get a feel for the performance of each supplier. Generally, other contractors, engineers, and architects should be able to give you input on the choices available in that particular area.

The majority of this discussion will be based on ready mix suppliers, not mobile mix trucks. However, mobile mix trucks can be a great alternative for certain jobs based on parameters, such as location (usually more remote jobsites) and amount of concrete needed. A mobile mix truck's quality and consistency is heavily dependent on the skill and experience of the driver operator.

A few key decision points for choosing a ready mix supplier are:

- Proximity to the jobsite (if one supplier is 5 minutes away and another is 45 minutes away, that is a huge difference, especially if the job specifications require placement within 90 minutes of batching);
- Willingness to work with you to get to a desired mixture design;
- Flexibility of schedule (availability of trucks);
- Quality and cleanliness of their trucks;
- Knowledge and demeanor of their drivers and staff;
- Extra (sometimes hidden) costs; and
- Price per yd^3 (m^3).

Notice that price was the last on my list of key factors. That is because we have found that most suppliers are very competitive on price. What sets the suppliers apart for our specific needs in the shotcrete industry is service. Service includes several different items.

Starting with the mixture design, it is crucial that the plant is willing to provide a mixture design to meet your needs/specifications. Shotcrete mixtures can be very different in composition compared to cast-in-place concrete mixtures. The ingredients are not different but the amounts of each ingredient are usually very different. It is not uncommon for a supplier/batch plant to have never seen or produced a shotcrete-specific mixture. Several times we have gotten pushback from suppliers saying that a mixture design will not work. That is where previous experience and documentation become important. We do our best to keep on file each mixture design that we use and the compressive strength cylinder tests that are taken (Fig. 1). We share this information with the supplier so that they have documentation for the future. Admixtures are critical in making a good shotcrete mixture and the supplier's ability to provide the correct admixtures in the correct dosages is very important.

Once a mixture is chosen, it is critical that the mixture is consistent from truck to truck. That is where batch recordings are necessary. Make sure the supplier can and will provide batch records for the specific quantities in every load. Not only do batch records give you the complete picture of what is in the truck but they also give you the


Fig. 1: Cylinder tests

information necessary to calculate how much water can be added to the mixture to stay within the specified water-cementitious material ratio (*w/cm*) (Fig. 2). Most jobs will require third-party testing and any reputable testing firm is going to require batch weights. We can not stress enough how important batch records are. They are a critical piece of information that is very often overlooked.

Quality and cleanliness of the trucks is a much bigger factor than most would think. We are not concerned by the outward appearance of the truck. We are only concerned about the inside of the drum—mainly the fins—and if they have excessive buildup on them (Fig. 3(a) and (b)). A dirty barrel with excessive buildup on the fins is not effective at properly mixing the concrete. Proper mixing is much more critical in very low *w/cm* shotcrete mixtures than it is with standard concrete mixtures. Trucks with excessive buildup on the fins will produce inconsistent concrete throughout the discharge cycle that leads to poor-quality, inconsistent in-place concrete. The consistency of a mixture is crucial when doing vertical and overhead work. We have rejected trucks and banned trucks from returning to jobs due to them not being clean enough to properly mix the concrete. How do you determine if a supplier has clean or dirty trucks? Take a look at some of their trucks and you will be able to get a feel pretty quickly about how clean their fleet of trucks is kept. We have found that suppliers who require the drivers to chip their trucks have much


Fig. 2: Batch recordings


Fig. 3(a): Clean truck


Fig. 3(b): Dirty barrel

cleaner drums than suppliers who do not make the drivers chip their own trucks.

Depending on job factors, such as temperature and volume, the ability to have a steady flow of trucks becomes increasingly important to the quality of the finished product. Fresh concrete is always preferred, and on some jobs concrete that is more than 90 minutes old may not be placed. Due to the slower nature of shotcrete placement, a lot of times 6 or 7 yd^3 (4.6 or 5.4 m^3) trucks provide needed flexibility for a particular job. I find that trucks that only have 7 yd^3 (5.4 m^3) are much more consistent throughout the mixture than trucks with 9 or 10 yd^3 (6.9 or 7.7 m^3) in them. I also prefer to completely pump my hopper down in between trucks to make sure that the concrete in the hopper of the pump is as fresh as possible. A supplier who has enough trucks available to get a quick cleanup load to complete a job is also a great benefit, as sometimes shotcrete jobs can be difficult to accurately calculate the amount of material needed due to irregular shapes and the amount of rebound or sluff that is removed once a particular shape is cut/sculpted.

The knowledge and temperament of the ready mix drivers is an often overlooked but key deciding factor. This information is much harder to come by than just a quick phone call or trip to their plant. Information about the drivers who work for a particular supplier is usually relayed from others' experiences and your own experience with a particular supplier. Drivers who show up with bad attitudes can really sour the mood of a jobsite, which leads to lowered productivity and quality.

Drivers who lack the knowledge of how to properly operate their trucks can be a big problem. There can be several key issues involved—from the driver's inability to keep the hopper full (which leads to surging at the nozzle), to overflowing the hopper and making a giant mess, to a host of other issues. We once had a driver who was chipping his truck with a hammer while discharging and letting big chunks fall into the pump. This caused a couple of blockages before we determined the root cause of the blockages. Needless to say, the driver was banned from ever coming to our job again. We have had numerous drivers who refuse to listen to instructions and would not spin the drum enough to adequately mix the concrete; they would then add water without permission, creating an unusable mixture.

Standby time and short load fees are a factor in choosing a plant, but not as big of a factor as those previously mentioned. If you have multiple suppliers that are all similar in the other deciding factors, a swing vote may be achieved by determining the cost differences in short load and wait time charges. Some other charges that may be a factor are color addition and cleanout charges, as well as returned material charges. Make sure to get a complete list of all applicable charges so there are no surprises. We have seen exorbitant charges for high-range water-reducing admixtures (upwards of \$20 per yd^3 [\$26 per m^3] for medium dosages) and other admixtures. If you are aware of these charges going into the job, you can choose to add some or all of the admixtures to the truck on-site to save money.

Price per yd^3 (m^3) can vary wildly depending on mixture, location, admixtures, and availability of materials locally. Make sure to get a quote in writing for your specific mixture design, including the admixtures. Some plants will quote you a low per-yard (meter) price but it will not include the necessary admixtures to make the mixture workable. Some plants will quote the material and the haul charge separately. Some plants will only allow for 3 minutes per yard (meter) of unloading time and then start the clock on wait time. As we all know, it is not feasible to place a 6 yd^3 (4.6 m^3) truck in 18 minutes from arrival on-site. It usually takes 10 minutes to get the mixture to a usable state before the discharge cycle even starts. This amount of time can increase with a supplier who does not understand slump and how to accurately gauge slump, and will not send the mixture as desired. We find it disheartening at how few suppliers are able to batch concrete based on a specific *w/cm*. Most will ask for the desired slump, but few will be able to consistently and accurately deliver as desired.

With all that being said, the best way to choose a supplier is to get a reference from another company that performs work similar to what you are doing. Their experience is the best gauge on how well a particular supplier will work for your particular situation. We find that most contractors are more than willing to share their experience regarding a particular supplier.

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

A Closer Look at the Benefits of Predampening

By Todd Ferguson

Much has been written on the benefits of predampening dry-mix shotcrete (gunite) materials before application; however, it is worth exploring these benefits in greater detail. The purpose of predampening is to add moisture content to dry shotcrete materials to ensure benefits during and after the project. Predampening is used in a diverse set of industries, including ground stabilization, refractory relining, tunneling, mining reinforcement, and bridge applications, to name just a few. Virtually any dry-mix shotcrete project benefits from the use of predampening materials. It is the industry "best practice" as stated in the ACI 506R-05, "Guide to Shotcrete," that "the crew should predampen the batch before introducing it to the shotcrete delivery equipment."[1]

Dry-Mix Shotcrete (Gunite) Materials

Dry-mix shotcrete is either pre-bagged, delivered by truck, or batched on-site. Available in a wide range of specifications, pre-bagged materials contain a binder cement, sand, some level of aggregates, as well as other additives, which are normally proprietary to their manufacturers. Otherwise stated, "dry, pre-mixed shotcrete consists of pre-blended aggregates (rock and sand) that are pre-dried to minimal moisture and mixed with accurate amounts of silica fume, set accelerator, steel fibers, and any other addition required."[2] Obviously, not all materials contain the same additives and only some contain steel fibers. Packaged dry shotcrete materials are devoid of moisture by design—they have undergone a drying treatment in their manufacturing so that they could be packaged. Premixed dry shotcrete materials offer inherent benefits of long shelf lives, consistent specifications, engineered production standards, and high early compressive strength and long-term compressive strength. Other materials used in dry-mix shotcrete may be delivered by ready mix or batched on-site with bulk sand and cement from bags or other storage containers.

Fig. 1: Dry-mix shotcrete nozzleman using predampened materials during a parking garage repair

Predampeners

The predampener is machinery consisting of a material hopper for loading pre-bagged materials and a combination auger/spray bar system that transfers materials as they are lightly misted with a water spray. The predampener's auger system allows this predampened material to fall into the receiving hopper of a dry-mix shotcrete (gunite) machine. Contractors use predampeners to add 3 to 6% overall moisture content to dry-mix material before it is loaded into a dry-mix shotcrete machine. Batching and mixing equipment is also available for those producing materials on-site. This equipment performs a dual function of proportioning materials and predampening. Otherwise, the contractor will use a dedicated predampener or special hydromix nozzle to add moisture. Hydromix nozzles of various configurations have been used in the industry. The traditional hydromix nozzle contains a single nozzle body, installed at a distance of 12 to 36 in. (300 to 900 mm) from the nozzle tip.

The benefits of predampening are worth exploring. Although predampening has been advised as a best practice by ACI and ASA, it would seem that until now we have yet to adequately correlate predampening benefits with the recommendations stated throughout ACI 506R. We will explore each benefit of predampening in the following, relating each to best practices while illustrating how they apply to safety.

Benefits of Predampening

- Higher-quality in-place concrete;
- Reduced dust around equipment and nozzle;
- Reduced rebound;
- Less wear on equipment;
- Greatly decreased static electricity; and
- Higher return on investment.

Fig. 2: Predampener shown with dry-mix shotcrete machine

Higher-Quality in-Place Concrete

Predampening in the dry-mix shotcrete process helps ensure uniformity[3] of in-place shotcrete, elevating the quality of the concrete structure. Uniformity can be seen in various stages of shotcrete production, both before and after materials are shot onto the surface. Before even reaching the nozzle, materials that are predampened will have better mixing and uniformity. Predampening reduces separation "of the dry aggregates and cement binders as the predampened material moves through the hose, which will result in a better finished product in place. Also, the dampened material accepts the water better when the entire amount does not have to be introduced at the nozzle."[4] Predampening leads to better uniformity of the in-place shotcrete because the material has started to mix before even reaching the nozzle. The material then undergoes additional mixing within the nozzle and is conveyed onto the construction surface. Predampened materials lead to consistent distribution throughout, giving a "more homogeneous moisture content to the in-place shotcrete."[2] A more homogenous material allows a less-variable, more evenly distributed strength in the resulting concrete. When the shotcrete project results in more structurally sound concrete, the risk of failure is minimized. This guarantees a safer environment for everyone who lives, works, and plays on that concrete structure.

Reduced Dust around Equipment and Nozzle

Health and safety of the crew is a priority. Predampening reduces dust, which limits workers' exposure to materials containing cement, silica fume, and other chemicals not compatible with the human body. In enclosed spaces such as refractories, tunnels, and mines where ventilation is minimal, dust could be a significant health concern. Dust is minimized at multiple points of the shotcrete operation when using a predampener, "greatly reducing dust at the machine as well as the point of placement."[3] The dry-mix shotcrete machine contains a material agitator and rotating feed system, which may create dust if using dry material right out of the bag or "super sack." Luckily, some dry-mix machines have suppression systems to help prevent excessive dust in these situations. The predampener is the most effective means of reducing dust around the machinery. That same dust "can contaminate adjacent structures, equipment, and grounds. This problem is especially aggravated on windy days."[1] In addition to reducing dust around the machinery, predampening minimizes dust at the nozzle. More research is needed to determine just how much dust reduction can be expected at the nozzle.

Reduced Rebound

Rebound is minimized in the dry-mix process by predampening. The benefit of reducing rebound can be realized by higher yields;—that is, less wasted material. Less rebound during the project also reduces labor time. "Rebound is aggregate and cement paste that ricochets off the surface during the application of shotcrete because of collision with the hard surface, reinforcement, or with the aggregate particles themselves. The amount of rebound varies with the position of the work, nozzle angle, air pressure, impact velocity, cement content, water content, maximum size and gradation of aggregate, amount of reinforcement, and thickness of layer. A blowpipe is sometimes used to remove and control rebound."[1] Because rebound primarily consists of aggregate, it should never be used in the structure. Instead, it must be removed either by shoveling, blow pipe, or other means. Less rebound means less labor time to remove it. Predampening reduces rebound by allowing the cement binders in the mixture to give a more adequate coating over the aggregates. These components will then remain more closely tied together with greater amounts of materials adhering to the shot surface. Excessive rebound can lead to undesirable shrinking and drying of the shotcrete, so it is important to keep it within acceptable limits. For example, an expected range of rebound losses on slopes and walls is 10 to 30%. By predampening, we can endeavor to achieve the highest yield of material used for in-place shotcrete while reducing labor and helping to create safer concrete structures.

Less Wear on Equipment

Predampening dry-mix shotcrete materials makes them less abrasive and increases the life span of various components in the dry-mix equipment setup. These components are recognized as "wear parts" and are primarily part of the dry-mix shotcrete machine, hose, and placement nozzle. They include the feed system wear plate, wear pads, discharge liner, internal material hose lining, placement nozzle washers, and liner. The expected life span of these components is well-known and documented. However, it is not known to what extent the life span of these parts is improved when using predampened materials. More research is needed to determine how predampening affects the life span of these parts.

Greatly Decreased Static Electricity

If dry-mix materials are conveyed with low moisture content, a static charge can build up in the hose and can give a shock to the nozzleman if using ungrounded delivery hose. Predampening can virtually eliminate this situation by adding the recommended 3 to 6% moisture content, which reduces the likelihood of static charges in the line. Static electricity building up in the system is not merely an annoyance to the nozzleman, it is a safety concern. The static electricity "can shock the nozzle operator and cause a loss of control of the nozzle."[1] The most important safety requirement for the nozzleman is that he retain control of the nozzle at all times, never pointing it in an unsafe direction and never setting it down while material or pressure are present in the lines. Decreasing static electricity through the use of predampening, the nozzleman will not be caught off guard by an electric shock, which could cause him to lose control of the nozzle. Any undue stress on the nozzleman could affect his performance and the overall quality of the shotcrete placement.

Return on Investment

In addition to all of the benefits mentioned previously, predampening is a sound business decision! Predampening equipment can "pay for itself in a relatively short time."[3] Better mixing and uniformity from predampening results in concrete that is more structurally safe and sound. Less dust keeps your crews in better health, potentially saving your business on health care premiums, not to mention the peace of mind you get by doing the right thing for your people. Reduced rebound allows you to get the most out of your material and improves your labor efficiency. Decreased wear on equipment may allow you to save on replacement parts for the dry-mix shotcrete machine and placement nozzle. Greatly reducing static electricity reinforces your commitment to safe working conditions. Predampening materials in the dry-mix process is not only a recommended procedure; it is also clearly a winning solution for quality, efficiency, safety, and profitability of your business.

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Industry Update

By Bill Drakeley

Many pool contractors—myself included—are skeptical of the majority of so-called "awards programs" in the pool industry. An unfortunate number of them are dependent on who you know, who won last year, and other factors that are mostly unrelated to the merit of the project itself. The American Shotcrete Association's Outstanding Shotcrete Project Awards program—now accepting entries—is an exception to this rule: it offers true credibility to the winner. By examining the inner workings of a structure, the ASA Outstanding Shotcrete Project Award levels the playing field and lets excellence receive the recognition it deserves.

The ASA Outstanding Shotcrete Project Award is not an easy one to win. It takes a certain amount of guts to reveal the ins and outs of a project, and it takes a certain kind of person to be willing to expose the interior workings of their product. In essence, it is your structural and aesthetic accountability that is being judged. That is precisely the kind of courage that we need in our industry to continue to reform and enhance its image. I encourage all pool builders using the shotcrete process to consider an application for an ASA Outstanding Shotcrete Project Awards in the Pool & Recreational category this year.

I also want to shine a spotlight on the four Position Statement papers currently in circulation by ASA:

- "Compressive Strength Values of Pool Shotcrete";
- "Definitions of Key Shotcrete Terminology";
- "Sustainability of Shotcrete in the Pool Industry"; and
- "Watertight Shotcrete for Swimming Pools."

Voted on and approved by the ASA Pool & Recreational Shotcrete Committee, the ASA Board of Direction, and the ASA Executive Committee, these Position Statement papers have taken the best of the variable thought processes and approaches from the industry's engineers, specifiers, builders, and other contractors and synthesized them into a common view. The result is four positions on the standards for quality in our industry that we can all stand by.

This has been a very successful program, and one that we will continue through the issuing of Position Statements on the following shotcrete-related phases and issues:

- "Forming";
- "Cold Joints (or lack thereof)"; and
- "Watertight Shotcrete for Swimming Pools: Part 2."

Like the shotcrete process itself, the Position Statement program is multi-faceted; we intend to continue to address key issues related to each phase of shotcrete installation. Building a personal library with these Position Statement

papers at the core will allow engineers, specifiers, and builders alike to employ accepted structural criteria for proper pool installations. This is the goal and intent of the program. All ACI and ASA standards are applied.

Current Position Statement papers can be accessed at **www.shotcrete.org/pages/products-services/shotcrete-resources.htm**.

Bill Drakeley *is President of Drakeley Industries and W. Drakeley Swimming Pool Company. Drakeley Industries is a shotcrete consulting firm that is dedicated to the training and implementation of the shotcrete process in regards to building water-retaining structures, ground support, and underground shotcrete application. Drakeley Pool Company is a design-build construction and service firm specializing in in-ground, high-end commercial and residential pools. Drakeley is an active member of ACI Committee 506, Shotcreting. He is the first ACI Certified Shotcrete Examiner from the pool industry nationwide. Drakeley is also an ACI Certified Nozzleman, ASA Technical Advisor, Chair of the ASA Pool & Recreational Shotcrete Committee, and serves as Treasurer to the ASA Executive Committee. His writings have been published in national and international trade magazines, including* Shotcrete, WaterShapes, Pool and Spa, *and* Luxury Pools. *In addition, Drakeley is a Platinum Member of the Genesis 3 Group, a licensed member of the Society of Water Shape Designers, and a member of the Association of Pool and Spa Professionals (APSP). He is also the Concrete/Shotcrete Instructor at the Genesis 3 Pool Construction Schools and NESPA Region 1 Show in Atlantic City. As an instructor and trainer, Drakeley has given lectures on shotcrete applications for various pool trade shows and for World of Concrete. Drakeley is an expert witness regarding shotcrete applications for the swimming pool industry.*

ASA Graduate Student Scholarship

2014-2015 Research Updates

The following are three short updates on graduate student research being undertaken by ASA's 2014-15 Graduate Student Scholarship recipients. The 2014-15 scholarships were announced at the February 2015 ASA Annual Meeting, Awards Banquet, and in the Winter 2015 issue of *Shotcrete*.

- Simon Bérubé is currently pursuing his MSc in civil engineering from Laval University, Quebec City, QC, Canada.
- Pasquale Basso Trujillo is a PhD Candidate at Laval University.
- Qian Wu is a graduate student majoring in civil engineering at the University of Texas at Austin, Austin, TX.

We hope they find the research into shotcrete-related topics rewarding, and we look forward to getting future updates on the research results.

***Simon Bérubé** received his BEng in civil engineering from **Laval University** in 2014 and is currently pursuing his MSc in civil engineering from the same university. His research project at Laval is centered on the kinematics of the shotcrete spray. The study aims to provide a better understanding of the rebound phenomenon and to express the impacting materials' energy within the spray. Bérubé plans to pursue a career in concrete and/or shotcrete projects, as his main field of interest is centered on cementitious materials.*

Research: Study of the Placement Process and Rebound of Shotcrete

Introduction and Background

Despite the constant evolution of new shotcrete equipment solutions and the recent progress in our understanding of the placement process,[1] a significant factor remains in the shotcrete industry: losses of materials by rebound. Even under the best conditions and by following the rules of good practice, losses will often account for 10% of the material; this amount can climb to 30% of the total quantity of materials used in adverse and difficult conditions. In this regard, it is safe to say that rebound losses have a significant financial impact on the use of shotcrete. This situation is not at all easy to deal with, because to have a chance at solving the problem of rebound, it requires an excellent comprehension of the placement process and the mechanisms behind it, access to shotcreting equipment, and a well-equipped laboratory. Indeed, the velocities and spatial distribution of the incident shotcrete particles are key parameters to understand rebound and impact energy on the substrate[2,3]; to gather this particular data requires quite the laboratory setup given the number of varying parameters in a shotcreting session (air, water and material flows, movement of the nozzle, distance, mixture design, and so on).

In the continuation of Ginouse's recent works[4] on the characterization of the shotcrete spray, this research project, conducted under the supervision of Marc Jolin at Laval University, will be focusing on the placement process of shotcrete and the phenomena that takes place during a spraying session. The main objective of this research is to further the understanding of conditions that facilitate a good inclusion of shotcrete particles, such as reduced rebound.

The first part of the experimental program tested a certain number of nozzles and recorded images of the spray produced by each of them. To achieve this, a high-speed imaging system provided numerous images for the calculation of particle velocities at up to 1250 images per second.

The second objective of the project was to characterize the parameters that combine sufficient velocity and kinetic energy to a particle at the moment it impacts onto the fresh shotcrete substrate in a way to ensure it is captured and does not rebound. To understand what conditions are favorable to the incorporation of incident particles into the substrate, the next step of the experimental program measured the spatial distribution of the particle's masses on the receiving surface to obtain the mass distribution of the accumulation of shotcrete materials produced by a fixed-point nozzle. Ultimately, we will connect velocities and masses to express the energy profiles of the particles at different distances from the nozzle. By knowing which particles adhere to the fresh substrate among various sections of the spray, it will be possible to establish which part of the spray is efficient and which part of it produces rebound. This will turn into a unique characterization tool to evaluate a given nozzle's efficiency at reducing rebound.

Significance of Research Project

Material losses from rebound represent significant financial losses in the shotcrete industry and represent as much as 30% of the total amount of materials used. By furthering the understanding of shotcrete rebound, it would be possible to lower the operational costs for the shotcrete sector of the construction industry. Following Ginouse's initial work,[1] this project describes the kinematics of shotcrete particles and their incorporation among the substrate within the spray for the first time. This understanding hopes to contribute solutions to lowering the loss of larger aggregates, which tend to rebound the most among all incident particles, thus affecting the mechanical properties of in-place materials. Additionally, by furthering the understanding of the parameters that allow a nozzle to be efficient, it would be possible to understand how to improve shotcrete equipment, especially nozzles, and mixtures to minimize rebound.

__Pasquale Basso Trujillo__ graduated from Universidad Panamericana in Guadalajara, México, in 2014, where he worked as a structural engineer apprentice, designing reinforced concrete and masonry low-rise buildings. He is now a PhD Candidate at __Laval University__ working under Marc Jolin's supervision on the "Development Length of Reinforcing Bars in Shotcrete." There, he also teaches a workshop on reinforced concrete design for undergraduate students.

Research: Development Length of Reinforcing Bars in Shotcrete Structures

Background and Industry Problem

Adequate encasement of reinforcing bars and other obstacles using shotcrete has always been a point of interest in the industry.[5-12] Achieving proper and complete encapsulation is strongly influenced by the selection of equipment and mixture design, but also to a great extent by nozzlemen experience and their skills; voids and/or sand pockets may be created behind obstacles if an improper placement technique is used.[5,8,11] This raises concerns when engineers design reinforced shotcrete structures, particularly when the development length of reinforcing bars in tension is calculated. Development length is defined as the additional length a reinforcing bar should be anchored in a given concrete member so it can develop its yield limit, assuring the concrete element's ductility.[13] In practice, engineers refer to standards such as ACI 318-14[14] or CSA A23.3-04,[15] which provide assessment and specific equations to calculate this extra reinforcement length. Moreover, modification factors have been added to the equation by other researchers over the years to account for conditions it originally did not consider, such as the reinforcing bar size[16,17] and use of epoxy-coated reinforcing bars.[18-20] However, both the equation and the modification factors have been formulated for cast-in-place (CIP) concrete only,[21-24] where defects located specifically behind reinforcing bars as sometimes found in shotcrete are believed to be unique to this method of placement. Despite its potentially significant impact on structural behavior and safety, the complexity and variability of steel-concrete bond in the presence of defects is the main reason this parameter has received very little attention. Thus, shotcrete as a method of concrete placement is not explicitly accounted for in the design codes for the development length calculation.

Over the last decade, this has often put structural engineers in a difficult position who, in view of a lack of fundamental comprehension of the phenomenon, have developed tools for the acceptance of shotcrete structures using CIP concrete specifications. The visual examination of the encapsulation quality of reinforcing bars (void size and contact perimeter with reinforcing bars) of extracted cores from structures is one of them.[25] Nevertheless, the acceptance criteria have been selected empirically—that is, based on experience rather than by a scientific and reliable assessment of the steel-concrete bond reduction whenever voids are present at their interface. In fact, the parameters that most affect bond with their presence are still not fully understood. Thus, the influence of encapsulation quality on reinforcement development length makes this subject a critical and much-needed research project to create durable and safe criteria for the design of reinforced shotcrete structures.

Objectives

The specific objectives of this research are enumerated as follows:

1. Understand the steel-concrete bond phenomenon (failure mode, stress-slip relationship, and ultimate bond force of

laboratory specimens) in the presence of different void sizes and location along of the steel-concrete interface.
2. Better comprehend the factors influencing the position and size of voids at the steel-concrete interface when using shotcrete, such as the reinforcing bar size being encapsulated and the experience of nozzlemen.
3. Integrate the steel-concrete behavior into a finite element model (FEM) to gain better comprehension of the phenomenon resulting from many other possible material properties and void and specimen geometry configuration.
4. Reliably assess and propose design criteria for design codes with regard of the calculation of the development length for shotcrete structures.

Research Significance

This research intends to answer a pressing question by engineers that has been present over the years in technical papers[7] and ACI meetings: How does one rigorously and accurately account for voids at the steel-concrete interface to reliably account for them in standards and design criteria? This will increase the confidence level by which civil engineers specify development lengths of reinforcement for shotcrete structures. It will also establish a guideline for them to anticipate development length based on nozzlemen experience, thus resolving an important aspect of structural safety for civil and mining infrastructure.

Qian Wu *is a graduate student majoring in civil engineering at the* ***University of Texas at Austin****, Austin, TX. She received her BS in civil engineering from both New York University Polytechnic School of Engineering, New York, NY, and South China University of Technologies, Guangzhou, China, in a 4-year dual degree program. Her research interests include magnetorheological cementitious materials, oil and gas well cementing, nondestructive testing of concrete, structural health monitoring, and fiber-optic sensing. Wu is an active member of ACI, ASA, ASCE, ASTM International, Chi Epsilon, and SPE. She also enjoys volunteering for UT Austin Engineering EXPO, EXPOLRE UT, and Austin Habitat for Humanity. Wu will complete her master's program in 2015 and will then continue to pursue her PhD degree in civil engineering with a focus on construction materials.*

Research: Industrial Applications for Cement-Based Magnetorheological Fluid

My research focuses on concrete and cement-based materials, their industrial application, and their evaluation and health monitoring.

One of my research areas focuses on the development of industrial applications for cement-based magnetorheological (MR) fluid. By applying a magnetic field, the rheological properties of this fluid can be tailored to fit the specific needs of various applications in both oil/gas as well as civil engineering industries. A research project that I have been involved with is the application of cement-based MR fluid in oil and gas well cementing to improve zonal isolation. A good cement job is the key to achieving successful zonal isolation. Insufficient zonal isolation could cause fluid migration, resulting in water aquifer contamination and loss of control of well pressure, shortening the life of wells and increasing the risk of blowout, which could result in economical loss and environmental disasters. Our project has already shown many positive results using the cement-based MR fluid in well cementing, and a related paper has been published in a recent Society of Petroleum Engineers (SPE) conference.

My research on cement-based MR fluid can be extended to the shotcrete application. Compared to conventional concrete, shotcrete shows superior hardened properties such as high strength, low permeability, and high durability, which interests me most. These advantages are extremely beneficial to applications such as structure repair and restoration, underground construction; and watertight structures such as pools, tanks, and domes. To improve the quality of shotcrete placement and to extend its areas of applications, a significant amount of research has been conducted that focuses on both the construction phase as well as the in-service performance of shotcrete. For example, during the shotcreting, the rebound level is a major concern affecting productivity, economy, and sustainability of shotcrete application. Also, just like other cement-based materials, shotcrete can crack after construction, threatening the bond strength, compressive strength, and durability of such systems. My preliminary study shows that there are a lot of potential benefits by applying cement-based MR fluid for shotcrete applications. For the construction phase, cement-based MR fluid can reduce the rebound level, increase the resistance to water washout, and reduce the fallouts due to vibration of the structures. For in-service structures, it is feasible to use cement-based MR fluid as a medium for nondestructive testing based on magnetic methods and long-term monitoring of structures.

My other research area focuses on using fiber-optic sensing technologies for structural health monitoring and non-destructive testing, especially for crack detection and monitoring. Cracking in concrete defeats its inherent advantages of low permeability and high strength and also influences its long-term durability. Thus, it's important to have the ability to detect and evaluate cracks, continuously monitor their growth, and explore their causes, which will significantly contribute to the repair of cracks in a timely manner.

I believe my research will contribute to the concrete and cement industries to improve the productivity, economy, durability, and sustainability of concrete and cement-based materials.

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Spring ASA Board and Committee Meetings

The ASA Board of Directors, along with the full slate of ASA standing committees, met on April 11, 2015, in Kansas City, MO. Nearly 30 active ASA corporate members, individual members, and visitors attended one or more of the committee meetings. We had excellent participation and discussion on a variety of topics, including new initiatives to support our Strategic Plan. Committees meeting were Pool & Recreational Shotcrete, Education, Marketing, Safety, Membership, and Publications. Significant actions by the Committees and Board of Directors included:


Axel Nitschke

1. Re-establishment of an Underground Committee. The committee will be chaired by Axel Nitschke, Vice President of GALL ZEIDLER Consultants, LLC;
2. Approval of a Marketing Committee recommendation to hire a consultant to produce rebranding options for ASA's logo and marketing material;
3. Discussion of publishing of a logbook for the upcoming ACI Nozzleman-in-Training program;
4. Continued support of Shotcrete Inspector training program development;
5. Support for an addition of three new ACI Nozzleman Shotcrete Examiners after they complete the ACI nozzleman examiner prerequisites; and
6. Reporting that ASA/ACI Nozzleman Certification activity is strong in the first quarter of 2015, and has seen a slight increase in dry-mix certifications over the previous year.

ASA routinely schedules our "Committee Day" immediately before the ACI Spring and Fall Conventions to allow our members to participate in both ASA and ACI shotcrete-related committees such as ACI 506 and C660. ASA's Fall Committee meetings are scheduled for November 7, 2015, in Denver, CO.

ACI C660 Shotcrete Nozzleman and C601-I Shotcrete Inspector Certification Programs

ACI Committee C660, Shotcrete Nozzleman Certification, recently approved revision of the Shotcrete Nozzleman Certification program policy. The revisions were sent to ACI's Certification Programs Committee (CPC) for final approval. The new policy should be in place later this year.


Randle Emmrich


Bill Drakeley

Long-time Chair of C660 Marc Jolin stepped down as Chair at the end of the Spring meeting. The committee Secretary, Randle Emmrich, has been confirmed as the new Chair, and will be joined by our current ASA Vice President Bill Drakeley as the new C660 Secretary.

Also of note, ACI CPC established a new certification committee for the Shotcrete Inspector certification program, C601-I. The committee had its first meeting in Kansas City, MO, and is chaired by Randle Emmrich. The committee is moving forward in establishing the documentation required to formalize the program.

Graduate Scholarships

You'll find in this issue short reports from the three recipients of the 2014-2015 ASA Graduate Scholarship awards. Their research is directly tied to benefiting the development of new shotcrete materials, investigating the impact of spray distribution and rebound, and confirming bond development for reinforcement embedded in shotcrete.

The 2015-2016 Graduate Scholarship Awards program will be opening shortly. If you have contact with students or professors in any concrete or construction-related university programs, please let them know about our program, which awards $3000 to up to three candidates each year. The primary requirements to be eligible are:

Applicants must be a full-time first- or second-year (post-bachelor's degree) graduate student during the entire scholarship year. Course work during a summer session will count toward the degree year. Applications will be accepted from anywhere in the world but graduate study must take place in the United States or Canada during the award year.

A link to the program materials is on our website at **www.shotcrete.org/pages/education-certification/grad-scholarships.htm**.

ASA Outstanding Project Awards

At our 2015 Annual Banquet, we presented our Outstanding Shotcrete Project Awards. In addition to receiving their awards and making short presentations at the ASA Annual Banquet in conjunction with World of Concrete, the winners were also highlighted in the Winter 2015 issue of *Shotcrete* magazine.

Now is the time for you to submit your project(s) for consideration in next year's awards. ASA's annual Outstanding Shotcrete Project Awards provide real-world applications of the exceptional advantages of placing concrete via the shotcrete process. This is a great marketing tool for your company and the great work you do. Our categories include: Architecture | New Construction, Infrastructure, International Projects, Pool & Recreational, Rehabilitation & Repair, and Underground.

We've made the online submittal process as straightforward as possible. The Official Entry Form and additional background information can be found on ASA's website at **www.shotcrete.org/pages/membership/project-awards.htm**.

International Bridge Conference—Pittsburgh, PA, June 2015

ASA will be participating in a Bridge Preservation workshop at the 2015 International Bridge Conference, running June 7-11, 2015, at the David L. Lawrence Convention Center in Pittsburgh, PA. The details of the workshop, to be held on June 11 from 1:00 p.m.-5:00 p.m., are as follows:

"This workshop session provides a detailed overview of proven bridge restoration and preservation techniques.

Topics include rapid bridge deck rehabilitation using hydrodemolition, life extension of concrete elements with the use of cathodic protection, structural restoration with shotcrete, and fast-curing bridge deck waterproofing systems. Each year maintaining agencies spend millions of dollars in bridge maintenance. This Bridge Preservation workshop will not only demonstrate substantial sustainability benefits but will also cover ways to reduce maintenance costs while minimizing disruption of traffic.

Speakers: Charles Hanskat, American Shotcrete Association, Farmington Hills, MI; Patrick Martens, Bridge Preservation and Inspection Services, Jefferson City, MO; Mohit Soni, Stantec, Boca Raton, FL; and Dirk Uebelhoer, Sika Services AGStuttgart, Baden, Württemberg, Germany."

Further details on the Conference and Workshops can be found at **www.eswp.com/bridge/index.htm**.

International Pool, Spa, and Patio Expo and Conference—Las Vegas, NV, November 2015

ASA is a co-sponsor of the upcoming International Pool, Spa, and Patio Expo, to be held in Las Vegas, NV, November 7-12, 2015. We will be exhibiting at the Expo to promote the use of shotcrete in pools. Also, ASA Vice President Bill Drakeley will be presenting an ASA Nozzleman Education session at the Conference. Potential nozzlemen or others interested in learning more of the details of producing quality shotcrete in a day-long seminar should consider attending. The session does qualify attendees for the ASA nozzleman education portion of our ASA/ACI Nozzleman Certification program.

More details on the show and conference can be found at **www.poolspapatio.com**. Registration will open this summer.

Alpbach Conference 2015

The 11th Shotcrete Conference took place in the Alpbach Conference Centre from January 29 to 30, 2015. Organizer Professor Wolfgang Kusterle welcomed approximately 260 guests. Participants value these now-traditional shotcrete conferences in Alpbach, Austria, for their interesting presentations as well as for the relaxed ambience.

Professor Jozef Jasiczak started the sequence of presentations with the story of Warsaw Museum of the Polish Jews. The structure of the museum included several very large multiaxially curved wall panels made of dry-mix shotcrete. A second presentation on the versatility of shotcrete for architecturally challenging projects showcased the construction of shotcrete walls which resemble natural stone masonry.

In the latter presentation, the audience learned about textile reinforcement of shotcrete, which is easier to embed than traditional reinforcing bar, requires less cover, and enables a higher degree of reinforcement. Details of shear reinforcement of long beams and protective layers for hydraulic structures were the subjects of two presentations.

Where shotcrete requires both high resistance to fire and explosions, reinforcement with extremely high fiber contents is required. One presentation described that such shotcrete can only be pumped and sprayed if batched with uncommonly high air contents. Two presentations, from Canada and England, discussed heavily reinforced structural shotcrete, with reinforcing bar diameters to approximately 1 in. (30 mm).

Calcite deposits in the drainage systems of road and rail tunnels have become a significant concern in Europe. One reason for such precipitations may be a high content of clinker in the mixture. Two presentations explained the mechanisms causing such deposits and discussed methods to control them.

In the session on testing, a presentation on various methods for the determination of early strength development reminded the audience of the limits and errors accompanying many of the test methods in use. A novel miniature shotcrete test device for the production and early-age evaluation of shotcrete mortars was introduced. Its intended use is the rapid and economical study of admixture-cement compatibility issues. An important refresher on correct nozzle direction, nozzle distance, and material velocity presented information on optimum spray conditions.

Many infrastructure tunnels have seen long years of service and require significant maintenance. Repair and maintenance may greatly extend the service life of tunnels if issues of percolation of acidic ground water, deicer salt exposure, frost attack, and surface contamination can be addressed thoroughly. Two related presentations offered details about cathodic corrosion protection for the Rendsburg tunnel and the use of white shotcrete for the Agnesberg tunnel. Several presentations also analyzed single-shell tunnel walls and the state-of-the-art in waterproofing technology. A presentation on the different and sometimes incompatible or ill-defined code requirements affecting shotcrete and spray-applied mortars illuminated the formal aspect of shotcreting.

Fig. 1: Prof. Kusterle welcomes 260 guests at the "Spritzbeton-Tagung 2015," Congress Centrum Alpbach (Photo: Kusterle)

Fig. 2: Curving wall panels of tinted shotcrete in the entrance area of the Museum of the History of Polish Jews, Warsaw (Photo: Josef Jasiczak, Poznan University of Technology)

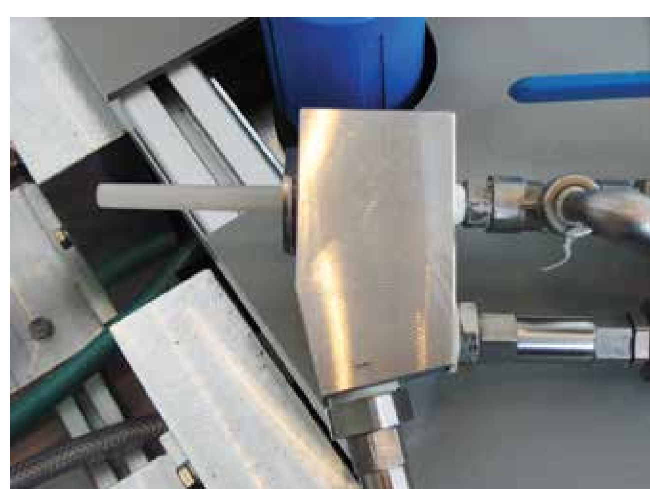


Fig. 3: Miniature nozzle of a laboratory mortar spraying and testing device (Photo: Kusterle)

A compendium of all publications is available on CD and can be ordered from Wolfgang Kusterle (spritzbeton@kusterle.net). As most of the original presentations are in German, *Shotcrete* magazine intends to prepare a more detailed summary in English, available in the second half of 2015.

Shotcrete for Underground Support XII

The 12th International Conference on Shotcrete for Underground Support (ECI SUS XII) will be held at the Grand Copthorne Hotel in Singapore, October 11-13, 2015. This event is organized by Engineering Conferences International (ECI) and supported by NTU-JTC Research Centre (NTU-JTC 13C), the Society of Rock Mechanics and Engineering Geology (SRMEG), International Tunnelling and Underground Space Association (ITA-AITES), and Studiengessellschaft für unterirdische Verkehrsanlagen mbH (STUVA). Visit **www.engconfintl.org**.

ECI SUS XII aims to pool the consolidated efforts from engineers, researchers, and project managers from across the world to share and update state-of-the-art technology and best practices in rock engineering, TBM, and deep excavation.

Topics

- Development in shotcrete technology for soft ground tunneling and subsea tunnels;
- Development in TBM, deep excavation, and underground space technology;
- Shotcrete reinforcement design;
- Mechanical properties of shotcrete under elevated temperature and corrosion environment;
- Methods and equipment for shotcrete installation;
- Laboratory tests, onsite quality control, and repair of shotcrete;
- Numerical simulation of tunnel rock support with shotcrete;
- TBM tunneling in challenging ground conditions;
- Development in rock tunneling and rock blasting;
- Grouting and water control for tunnels;
- Application of Eurocodes in rock tunneling;
- New technology in rock exploration and site investigation;
- Developments in fiber-reinforced shotcrete; and
- Case studies.

QUIKRETE Launches New Website with Advanced Capabilities

In 2014, nearly 4 million people visited **www.QUIKRETE.com** for building, repair, remodeling and home improvement inspiration, education, and other helpful project and product information. Building on its proven value as a leading online resource for homeowners and construction professionals, The QUIKRETE® Companies launched a new, advanced website featuring a comprehensive set of tools and information for an array of concrete, masonry, and stucco projects. In addition, the new website is mobile-responsive so that users have access on a desktop computer, laptop computer, smartphone, or tablet.

"Over the years, we've enhanced QUIKRETE.com based on extensive research and insights from homeowners and contractors with the goal of providing the best possible user-experience," said Frank Owens, Vice President of Marketing for The QUIKRETE Companies. "The new website provides homeowners and contractors different experiences through navigation that leads to information that fits their needs. For example, our how-to videos are very popular with homeowners while contractors are more interested in technical product info, so we've made that specific content easy for each visitor to find. In addition, our data shows that almost 50% of visitors to QUIKRETE.com are on mobile devices or tablets, so it was a priority to make the latest version mobile-responsive."

All visitors to www.QUIKRETE.com are immediately welcomed by a rotating collection of dynamic home improvement and commercial projects illustrated through product call-outs and bold images. While no content is exclusive, navigation does provide homeowners and construction professionals a clear path to desirable information. The "For Homeowners" path features concrete, masonry, and stucco project ideas, product descriptions, and step-by-step how-to application videos. The "For the Pro" path features information for commercial, residential, and municipal projects, including product performance and technical data, guide specifications, and case studies.

QUIKRETE anticipates heavy traffic from both homeowners and contractors to the Quantity Calculator, which follows a trend dating back nearly two decades when www.QUIKRETE.com was originally launched. The website also features a QUIKRETE Company Store, FAQs (Frequently Asked Questions), Customer Service, Media Center, and Dealers Only Area. In addition to www.QUIKRETE.com, more information on QUIKRETE products and projects is available on Facebook, Twitter, Pinterest, and YouTube.

Holcim & Lafarge Merger

The Boards of Directors of Holcim and Lafarge are pleased to announce that they have reached an agreement on revised terms for the merger of equals between both companies.

Both parties agreed on a new exchange ratio of nine Holcim shares for 10 Lafarge shares.

There will be a new Chief Executive Officer for the combined group. Wolfgang Reitzle and Bruno Lafont will be non-executive Co-Chairmen of the Board. The two Co-Chairmen will be working closely together to make this merger a success. Beat Hess will be Vice-Chairman of the Board.

The Holcim shareholder resolutions required to implement the combination are expected to be presented to a Holcim shareholders meeting on or about May 7, 2015.

Lafarge and Holcim have agreed that, subject to shareholder approval, the new company will announce a post-closing scrip dividend of one new LafargeHolcim share for each 20 existing shares.

With this amended agreement, the project to combine Lafarge and Holcim to become the most advanced company in its industry has taken another important step forward. Both companies are continuing to work intensively on preparing the closing of the transaction and the successful integration post-merger.

Wolfgang Reitzle, Chairman of Holcim said, "I am very pleased that we are now able to proceed with our project to create a truly outstanding global leader in building materials. Bruno Lafont and I will work closely together to ensure that the value creation potential of this merger will be realized for the benefits of all shareholders. I want to highlight that Bruno has made a tremendous contribution to getting us this far and that I am very confident in our ability to work together in the new Board."

Bruno Lafont, Chairman and CEO of Lafarge said, "We are crafting a new leader in the building materials industry focusing on customers and innovation. The new company will gather best-in-class teams of our sector with the strength of our two combined companies. It creates a new business model with outstanding cash flow generation capabilities and reduced capital intensity."

Certain key shareholders of both companies have confirmed their support for the revised merger terms. The Parties expect the transaction to close in July 2015.

Holcim is one of the world's leading suppliers of cement and aggregates (crushed stone, gravel, and sand) as well as further activities such as ready mixed concrete and asphalt services. The Group holds majority and minority interests in around 70 countries on all continents. More information is available on Holcim's website, **www.holcim.com**.

A world leader in building materials, Lafarge employs 63,000 people in 61 countries, and posted sales of €12.8 billion in 2014. As a top-ranking player in its cement, aggregates, and concrete businesses, it contributes to the construction of cities around the world, through its innovative solutions providing them with more housing and making them more compact, more durable, more beautiful, and better connected. With the world's leading building materials research facility, Lafarge places innovation at the heart of its priorities to contribute to more sustainable construction and to better serve architectural creativity. More information is available on Lafarge's website, **www.lafarge.com**.

Industry Personnel

Eric Olsen Appointed as Future CEO of LafargeHolcim

Eric Olsen

In the framework of their proposed merger of equals, and following a proposal from Lafarge Chairman and CEO Bruno Lafont, the Boards of Directors of Lafarge and Holcim have approved the appointment of **Eric Olsen** as future Chief Executive Officer of LafargeHolcim, to be in office as from the closing of the merger project.

He joined Lafarge North America in 1999, as Senior Vice President for Strategy and Development, leading the integration of Blue Circle's North American operations and restructuring cement assets. Since 2001, he served as both President, North-East Cement region, and Senior Vice President, Purchasing. Since 2004, Olsen served as Chief Financial Officer and Senior Vice-President for Lafarge North America.

From 2007 to 2012, he served as Executive Vice President, Organization and Human Resources of Lafarge Group. In this role, he led the integration of the Egyptian Orascom, a major acquisition with operations in Africa, Middle East and Asia. Olsen also led the 2012 reorganization of the Group with a focus on country organization around end-market segments.

Prior to Lafarge, Olsen started his career in the field of M&A at Deloitte & Touche, Banque Paribas and was one of the managing partners of Trinity Associates for 6 years.

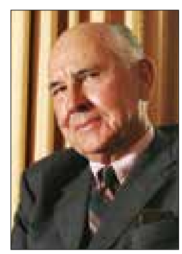
He is a business graduate from the University of Colorado, Boulder, CO, and received his MBA from HEC International Business School in Paris, France.

Eric Olsen is a Board Member of Cimpress N.V., chairing its compensation committee, and is a member of its audit committee. He is the Chairman of the Board for the American School of Paris.

Commenting on the appointment, Wolfgang Reitzle, Chairman of the Holcim Board and future Co-Chairman of LafargeHolcim, said, "I very much welcome Eric Olsen as future CEO for LafargeHolcim. With his broad international experience and insights in key markets, he is best positioned to lead the combined company for the benefit of employees, shareholders, and customers. Bruno and I will support Eric Olsen in creating a new joint culture that will be the key driver for our premier competitive position."

Lafarge Chairman and CEO and future LafargeHolcim Co-Chairman Bruno Lafont said, "Eric has been proposed as future CEO of LafargeHolcim both for his personal and professional qualities. He has a deep knowledge of our activities, clients and markets. He is driven, with energy and determination. He is a true leader, with the ability to bring the teams together to drive a strong value creation culture for our shareholders. I have every confidence in his ability to deliver the synergies announced and ensure the development and the success of LafargeHolcim."

A. James Clark, 1927–2015



A. James Clark

A. James Clark died on March 20, 2015. A legendary builder, Clark led Clark Construction Group for decades. His remarkable vision and direction transformed a local construction company into one of the largest and most respected general contractors in the United States.

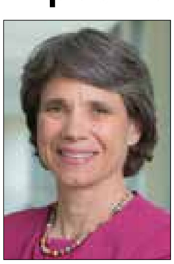
A graduate of the University of Maryland's School of Engineering, College Park, MD, Clark began his construction career in 1950 with The George Hyman Company (later to be renamed Clark Construction). Within two decades, he ascended through the company ranks and assumed the role of President and Chief Executive Officer. During his 64-year tenure, Clark dramatically expanded the Clark Construction Group's service offerings and geographic footprint. The company currently has more than a dozen regional offices across the country, and more than 4000 employees.

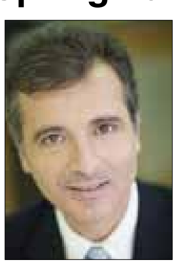
Perhaps one of Clark's greatest legacies to the company and its employees is that he planned thoroughly and thoughtfully for the day when he was no longer at the company and carefully transitioned the leadership of the company to where it is today.

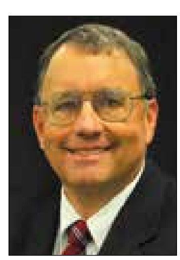
Clark left an indelible mark on the company and the construction industry. Equally as important as the contributions he made to the built environment, is the tremendous impact he made through his philanthropy. A man of great principles, Clark believed firmly in the importance of giving back to the community. Leading by example, he taught those around him to do the same.

Clark Construction Group is grateful for the contributions Clark made to the organization, and for his exemplary lessons in leadership and humanity. While he will be dearly missed, his legacy will endure, both through his extraordinary charitable giving and the big blue Clark signs that dot the landscape.

ACI Officers for 2015-2016 Appointed at The Concrete Convention and Exposition – Spring 2015


Sharon L. Wood


Kahaled Walid Awad


Michael J. Schneider

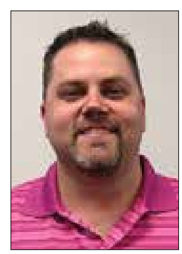
At the conclusion of The Concrete Convention and Exposition – Spring 2015 in Kansas City, MO, **Sharon L. Wood**, Dean of Cockrell School of Engineering and the Cockrell Family Chair of Engineering No. 14 at The University of Texas at Austin, Austin, TX, was appointed ACI President for 2015-2016, as elected by the ACI membership. **Kahaled Walid Awad**, the Chairman and Founder of ACTS, a material and geotechnical consulting firm based in Beirut, Lebanon, begins his 2-year term as ACI Vice President, joining **Michael J. Schneider** (Senior Vice President and Chief People Officer, Baker Concrete Construction, Inc., Monroe, OH) in his second year as the Institute's other current Vice President.

Wood succeeds **William E. Rushing Jr.**, (Vice President, Waldemar S. Nelson & Co., Inc., New Orleans, LA) ACI President 2014-2015, who will now assume a position on the ACI Board of Direction as a Past President member. His position replaces **Kenneth C. Hover**, ACI President in 2010-2011. Rushing joins **James K. Wight**, ACI President in 2012 and **Anne M. Ellis**, ACI President in 2013, to complete the requisite three Past Presidents of ACI serving on the Board as stipulated by the Institute's Bylaws.

Four new members were also elected to serve 3-year terms on the ACI Board of Direction at this time. They are:

- **JoAnn P. Browning**, The University of Texas at San Antonio, San Antonio, TX;
- **Cesar A. Constantino**, Titan America LLC, Roanoke, VA;
- **Kimbery Kayler**, Constructive Communication, Inc., Dublin, OH; and
- **Roberto Stark**, Stark+Ortiz, S.C., Mexico City, Mexico.

Mesa Industries Continues Growth with Three New Hires


James Chadwick


Bryan Koshover


Joy Salaz

James Chadwick joins Mesa Industries as Strategic Sourcing Manager, where he will lead the daily interaction of the purchase order system and manage the best practices for procurement. Before joining Mesa Industries, Chadwick worked as a Senior Buyer for Luxottica. He brings significant experience in sourcing and vendor management to the Mesa Industries team.

Bryan Koshover joins as the Marketing Manager and will play a key role in further contributing to the growth goals of the organization as well as lead branding initiatives. Prior to joining Mesa Industries, Koshover was Director of Marketing for American Health Associates where he led marketing and branding efforts.

Joy Salaz joins Mesa Industries as the ERP Business Applications Analyst and will be in charge of executing performance improvement initiatives across the organization through the optimal use of third-party business solutions. Salaz comes to Mesa Industries from Champion Windows and has a proven track record in successful ERP System Implementation.

Mesa Industries is a leading manufacturer of products for refineries, storage tank facilities, and specialized construction industries with over 45 years of experience delivering quality, American-made products. Mesa Industries is a certified women-owned business through the Women's Business Enterprise National Council (WBENC) with headquarters in Cincinnati, OH, and additional offices in Houston, TX, and Monrovia, CA. Mesa Industries is the parent company for ASA Corporate members Airplaco and Gunite Supply & Equipment Co. Visit **www.mesa-intl.com**.

Shotcrete Calendar

JUNE 7-11, 2015
The International Bridge Conference
David L. Lawrence Convention Center
Pittsburgh, PA
The Bridge Preservation workshop, including an hour-long shotcrete session, is scheduled for presentation on Thursday, June 11 from 1:00 pm-5:00 pm (subject to change)
www.eswp.com

JUNE 14-17, 2015
ASTM International Committee C09, Concrete and Concrete Aggregates
June 2015 Committee Week
Marriott Anaheim
Anaheim, CA
C09.46 Shotcrete Committee meets Monday, June 15 from 10 am-12 noon
www.astm.org

JULY 20-24, 2015
PCA Professors' Workshop
Portland Cement Association
Skokie, IL
The Professors' Workshop is designed to provide faculty in engineering, architecture, and construction management programs the tools to teach the latest developments in concrete design, construction, and materials. ASA will present a class on shotcrete at this week-long conference.
www.cement.org

OCTOBER 14-16, 2015
ICRI 2015 Fall Convention
Theme: "Modern Trends in the Repair Industry"
Hilton Ft. Worth
Ft. Worth, TX
www.icri.org

NOVEMBER 7, 2015
ASA Fall 2015 Committee Meetings
Sheraton
Denver, CO
www.shotcrete.org

NOVEMBER 8-12, 2015
The ACI Concrete Convention and Exposition
Theme: "Constructability"
Sheraton
Denver, CO
www.concrete.org

NOVEMBER 10-12, 2015
2015 Pool | Spa | Patio Expo
Mandalay Bay Convention Center
Las Vegas, NV
www.poolspapatio.com

DECEMBER 6-9, 2015
ASTM International Committee C09, Concrete and Concrete Aggregates
Marriott Tampa Waterside Hotel
Tampa, FL
www.astm.org

FEBRUARY 1, 2016
ASA Committee Meetings at World of Concrete
Las Vegas Convention Center
Las Vegas, NV
www.shotcrete.org

FEBRUARY 1-5, 2016
World of Concrete 2016
Las Vegas Convention Center
Las Vegas, NV
www.worldofconcrete.com

MARCH 16-18, 2016
ICRI 2016 Spring Convention
Theme: "Maintenance and Protection in Harsh Environments"
The Condado Plaza Hilton
San Juan, Puerto Rico
www.icri.org

APRIL 16, 2016
ASA Spring 2016 Committee Meetings
Hyatt & Frontier Airlines Center
Milwaukee, WI
www.shotcrete.org

APRIL 17-21, 2016
The ACI Concrete Convention and Exposition
Hyatt & Frontier Airlines Center
Milwaukee, WI
www.concrete.org

JUNE 26-29, 2016
ASTM International Committee C09, Concrete and Concrete Aggregates
Chicago Marriott Downtown
Chicago, IL
www.astm.org

The Hidden Danger of Noise

Shotcrete workers are subject to noise, much of which is at potentially dangerous decibel levels

By Derek and Amanda L. Pay

Hearing is one of the most important senses that we have, and one of the easiest to permanently damage. According to the Centers for Disease Control and Prevention, "Occupational hearing loss is one of the most common work-related illnesses in the United States. Approximately 22 million U.S. workers [are] exposed to hazardous noise levels at work….An estimated $242 million is spent annually on worker's compensation for hearing loss disability."[1] The use of hearing protection is one of the most overlooked pieces of personal protective equipment (PPE). Shotcrete workers working without effective hearing protection are exposed to potentially damaging noise levels.

How dangerous are these noise levels? Previous studies regarding worker exposure rates have been derived from common construction job site exposure. Pump operators, finishers, and especially nozzleman and blow pipe operators continuously use some of the loudest construction equipment in operation today. Over the last 2 years, research on shotcrete worker noise exposure rates was conducted by Derek Pay and his wife Amanda Pay, an audiologist specializing in hearing conservation.

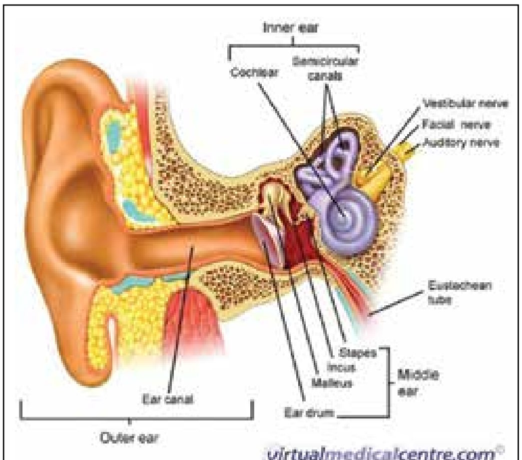


Fig. 1: Anatomy of the ear

They researched multiple environments designed to generate data on noise levels for various real-world jobsites. Data was collected using a noise dosimeter fitted to shotcrete workers over the span of their exposure time. The unexpected results of these tests clearly illustrate the acute need for hearing protection amongst shotcrete workers.

The Decibel

A unit of sound is measured by a decibel. A decibel measures the loudness or intensity of a sound. Once sound hits the ear, bones behind the eardrum begin to vibrate within the middle portion of the ear. The sound then travels to an area called the inner ear. Damage from noise exposure occurs in an area of the inner ear called the cochlea (refer to Fig. 1). The cochlea contains hairlike sensory receptor cells that transmit the acoustic message to the auditory nerve, which then sends it up to the brain. Damage occurring within the cochlea is permanent and is labeled sensorineural hearing loss. Unfortunately as of now, there is no known cure for sensorineural hearing loss.

For this experiment, we were interested to know at what point in the workplace, and for what period of time, could our ears be exposed to such sound levels before nerve damage may occur. Noise level and exposure time are key factors for possible permanent hearing loss.

The Occupational Safety and Health Administration (OSHA) provides us with a table (refer to Table 1) using A-weighted sound levels that calculate decibel levels (listed on left side of table) and length of time (listed on right side of table in hours going down to seconds) that an ear can be exposed to before nerve damage may occur. This chart illustrates, as the intensity level of sound increases, safe exposure time decreases.[2]

The Experiment

The experiment focused on three typical environments in which shotcrete workers may be exposed. In each environment, the nozzleman was fitted to a Q-200 noise dosimeter device manufactured by Quest Technologies (refer to Fig. 2(a) and (b)). The probe was placed near his ear for the duration of his work day. The device is designed to measure and record data on the exact sound pressure levels and decibel levels reaching the worker's ear.

The first test environment was a jobsite including a soil nail tieback wall in an open area with a maximum height of 65 ft (20 m) while in a man basket. The device displayed data for the 8-hour work day. Collected data revealed that the nozzleman was subjected to an average of 93 decibels. According to Table 1, at 93 decibels constant noise, ears are safe for only 5.3 hours before permanent hearing loss can occur.

The second environment was an indoor seismic retrofit project. This project consisted of tight working conditions creating a less-than-ideal acoustic environment. The nozzleman was on the job for 10 hours and exposed to an average of 95 decibels. The device recorded an exposure level of more than double the allotted safe listening time of 4 hours.

The final environment involved an outdoor residential swimming pool. The nozzleman worked for 10 hours with an average exposure level of 92 decibels. Again, the device recorded levels that are considered safe for only 6.1 hours.

During the experiment, sound levels were also measured in the same manner for a pump operator. With all three environments, the same pump was used and the pump operator was subject to a shocking average of 104 decibels with occasional peaks of up to 110 decibels when standing at the controls. The operator was at an extremely high risk for hearing damage given the amount of time of his exposure. With his average of 104 decibel exposure, in only 1.1 hours permanent nerve damage may begin to occur.

Results of this study conclusively prove that shotcrete workers are in very real danger of serious and permanent hearing loss. The solution to keeping our ears safe and conserving our hearing can be as simple as wearing effective protection designed for the expected exposure rate. The importance of wearing effective hearing protection during working hours cannot be overemphasized. The National Institute for Occupational Safety and Health (NIOSH) recommends using hearing protectors in all situations where dangerous noise exposure cannot be controlled or eliminated.

Table 1: OSHA Noise Exposure Computation, Table G-16A

A-weighted sound level, L (decibel)	Reference duration, T (hour)	A-weighted sound level, L (decibel)	Reference duration, T (hour)
80	32	106	0.87
81	27.9	107	0.76
82	24.3	108	0.66
83	21.1	109	0.57
84	18.4	110	0.5
85	16	111	0.44
86	13.9	112	0.38
87	12.1	113	0.33
88	10.6	114	0.29
89	9.2	115	0.25
90	8	116	0.22
91	7.0	117	0.19
92	6.1	118	0.16
93	5.3	119	0.14
94	4.6	120	0.125
95	4	121	0.11
96	3.5	122	0.095
97	3.0	123	0.082
98	2.6	124	0.072
99	2.3	125	0.063
100	2	126	0.054
101	1.7	127	0.047
102	1.5	128	0.041
103	1.3	129	0.036
104	1.1	130	0.031
105	1	—	—

Fig. 2(a): Dosimeter ear probe

Fig. 2(b): Dosimeter

"Of all of the regrettable things of working as a shotcrete nozzleman for more than 25 years, it is the perceived lack of importance I have given to basic personal protective devices (PPDs). Continuous, preventable exposure to our very loud work environment has caused irreversible damage that I must live with daily.

We all share the belief that we are somehow insulated from many common work hazards. Please consider how we take hearing for granted in our daily lives. Permanent hearing damage is preventable by the use of inexpensive ear protection."

—Oscar Duckworth (regular *Shotcrete* magazine contributor)

There are many different types of hearing protection: foam earplugs, custom earplugs, hard hat mounted over ear covers, and circum-aural headsets. Manufacturers of these products include a noise reduction rating (NRR) number that tells us to define how much sound attenuation the product provides (refer to Fig. 3(a) and (b)). For example, a common manufacturer of foam inserted earplugs have an NRR rating of 32, meaning when worn properly it will block out 32 decibels of overall loudness. Attenuating that much noise would bring our nozzleman and pump operator into a much safer noise exposure level, dramatically lowering their risk of permanent hearing damage.

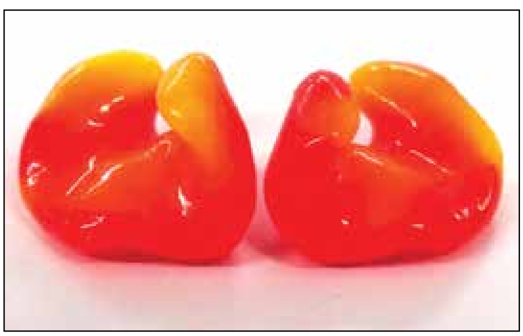


Fig. 3(a): Custom-molded earplugs

Fig. 3(b): Manufacturer's details on foam earplugs

Protecting our hearing is vitally important to our quality of life. Shotcrete workers are exposed to high-intensity levels of sound for long periods of time. It is essential we make hearing protection a high priority while on the job.

References

1. "Workplace Safety & Health Topics—Noise and Hearing Loss Prevention," Centers for Disease Control and Prevention, Atlanta, GA, 2014, http://www.cdc.gov/niosh/topics/noise/. (last accessed March 30, 2015)

2. "Noise Exposure Computation," Occupational Safety & Health Administration, Washington, DC, 2015, https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9736. (last accessed March 30, 2015)

Derek Pay *is the President and CEO of Oceanside Construction in Salt Lake City, UT. He received his BA from the University of Utah, Salt Lake City, UT, and has been in the shotcrete industry for over 10 years. He is a certified nozzleman in vertical and overhead techniques and currently installs shotcrete throughout the Intermountain west.*

Amanda L. Pay*, AuD, has been a clinical audiologist for 10 years, working in various areas such as Washington, DC, and currently practices at Mountain West Ear, Nose, and Throat in Salt Lake City, UT. She received her BS in speech pathology and audiology and her MS in audiology from the University of Utah and her doctorate (AuD) degree from Salus University, Elkins Park, PA. She is a Fellow in the American Academy of Audiology.*

New ASA Members

CORPORATE MEMBERS

Cipriano Landscape Design & Custom Swimming Pools
www.njcustomswimmingpools.com
Mahwah, NJ
Primary Contact: Chris Cipriano
chris@plantnj.com

Concrete Strategies
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Continental ContiTech
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dcielocha@mcgillrestoration.com

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Primary Contact: Lawrence I. Masserant
lcmasserant@midamericangroup.com

Revolution Gunite
www.revolutiongunite.com
Burlington, NC
Primary Contact: Ryan Oakes
info@revolutiongunite.com

Sorouh Al-masharee Ready Mix (Sarmix)
www.sarmix.com
Riyadh, Saudi Arabia
Primary Contact: Abdul Aziz Alrajhi
abdulaziz@sarmix.com

South Island Shotcrete Ltd.
www.southislandshotcrete.co.nz
Christchurch, NS, New Zealand
Primary Contact: Doug Haselden
doug@southislandshotcrete.co.nz

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Dupont, CO

Antonio Lima
Lime Group Const. Ltd.
Toronto, ON, Canada

Michael Nantz
Elite Concepts, Inc.
Lewisville, TX

Kaushal Parikh
Impact Floors India Pvt. Ltd.
Mumbai, Maharashtra, India

Rob Sangers
Sangers Shotcrete
Glenburnie, ON, Canada

PUBLIC AUTHORITIES & AGENCIES

Duane Piepho
Minnesota DOT
Owatonna, MN

STUDENTS

Menu Bruce
Quebec, QC, Canada

Aabid Hasan
Jaipur, NS, India

Nationwide Shotcrete, Inc.

Established in 2006 by shotcrete industry veteran Jon Harpole, Nationwide Shotcrete, Inc. (NSI), began as a family-owned and -run company specializing in small commercial projects. After spending several years honing their craft within the greater Southern California area, NSI began expanding its reach both north and south and now serves all of California, from San Diego to Sacramento. Today, NSI is an industry leader and innovator managing projects ranging from retaining walls to multi-million-dollar, multi-level parking structures and seismic retrofits.

As veterans in the shotcrete industry with three decades of experience, the Harpole Family has developed groundbreaking techniques to revolutionize the shotcrete industry. They constantly strive to find more efficient ways to place and finish shotcrete. Even down to their revolutionary process of cleaning up and disposing of rebound waste, NSI never rests until every aspect of every project is handled with precision and punctuality.

At NSI, we treat each client and each project with the same amount of professionalism and care. It is our "client-first" mission statement that has earned NSI several long-standing relationships through the years. We place a high value on each of these relationships and treat each client and every project, small or large in scope, with the same dedication and focus. The goal is to assist our clients in exceeding their schedule and budgetary goals while maintaining the highest-quality level of shotcrete in the industry.

Today, NSI is led by President Jon Harpole and Vice-President Jordan Harpole. General Superintendent Gene Lamberth and Operations Manager Kalo Franklin oversee statewide field operations. Tracy Thomas, Dan Franklin, Larry Klein, Paul Mendoza, and Jake Hinck make up the Project Management, Estimating, and Sales Team.

Recent notable projects include:

Sacramento Arena ESC

The new Sacramento Arena Entertainment and Sports Complex (ESC) will be the future home of the Sacramento Kings. This project is the spark to the light that will revitalize Sacramento's

Sacramento Arena ESC

downtown. Sacramento Arena ESC, which will take up several city blocks between J St / L St and 5th St / 7th St, is being built on a substantial portion of Downtown Plaza. This project was split into two phases—foundation and superstructure—with each having a separate concrete contractor, of which NSI was selected to work on both phases. The shotcrete walls on this project totaled 2300 yd^3 (1759 m^3), with hard-trowel finish on walls over 30 ft (9 m) in height for the perimeter and shear walls in the arena itself along with rehabilitating an adjacent existing structure with additional shear walls.

Metropolis Phase 1, Los Angeles

The Metropolis project occupies one city block of what used to be surface parking lot nestled between the Financial District and L.A. Live. Phase 1 consists of a 38-story luxury condominium tower and a 19-story hotel. Webcor Builders was selected as the General Contractor and Webcor Concrete performed all the structural concrete for the project. NSI was hired to place the subterranean retaining walls. After extensive preconstruction testing, we were also awarded a portion of the interior concrete walls, 8000 psi (55 MPa) shear walls, and pilasters. The project has very limited staging and virtually no street access, which means we were constantly pumping from longer-than-desired distances and having to use creative thinking to get the rebound waste out of the project on a daily basis while still wet. In addition, the site would not allow for a traditional tie-back shoring system on some of the elevations and we had to work around an unusually high amount of cumbersome corner braces, rakers, and pipe struts. The NSI Safety Team worked extensively in conjunction with Webcor's Safety Team to implement a safe, yet functional full-height scaffolding system that allowed us to help accelerate the below-grade schedule. Our walls ranged from 8 to 18 in. (203 to 457 mm) thick and contained integral pilasters and corbel beams, which took a combination of extra wires, reinforcement, and creative formwork to facilitate.


Metropolis Phase 1, Los Angeles

Expertise and experience. Unmatched quality. Groundbreaking innovation. "Client-First" service. These principals are the foundation for our continued success and the driving reasons for our ever-growing reputation as a world-class shotcrete organization. They remain the core elements that make for a first-rate shotcrete experience on projects for owners, general contractors, concrete contractors, and design teams statewide.


Office Team

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Blastcrete Equipment Company Upgrades 2200 Pan Mixer for Greater Efficiency

Blastcrete Equipment Company has upgraded its 2200 lb (998 kg) capacity Pan Mixer for greater efficiency, easier maintenance, and faster mixing speeds. The company designed the 2200 Pan Mixer specifically for refractory installations and manufacturing precast refractory shapes. It can mix up to 1 metric ton (1.1 tons) of refractory castable in 2 minutes or less. In addition, the mixer can be used for dry blending materials before water is added.

The new design increased the unit's maximum mixing speed from 30 to 45 rpm, which reduces mixing times from 5 to 2 minutes or less. It also has a variable frequency drive, which allows users to adjust the unit's mixing speed from 0 to 45 rpm in both forward and reverse.

The upgraded design also increases the pan mixer's efficiency. To avoid power loss that occurs when using hydraulics, the 40 hp electric motor couples directly to two gearboxes. By eliminating costly hydraulic components and the upkeep they require, Blastcrete has made the 2200 Pan Mixer more economical to purchase and maintain. An extension ring above the mixer was added to prevent material loss or spillage during loading or the mixing process, and a Fill-Rite water meter and 20-gauge dousing bucket allow for quick and accurate water filling. Additionally, a new bag ripper improves safety and efficiency by automatically opening bulk bags over the mixer.

The mixer's durable, tubular-steel frame includes a 15 ft^2 (1.4 m^2) operator platform and a user-friendly control panel for easy operation. Blastcrete offers a platform mixer extension so customers can discharge the mixer at various heights. A 3 hp electric motor with a hydraulic power unit opens the bottom discharge door so material free flows into a pump or mortar pan to be transferred to a form.

The 2200 Pan Mixer also features a hydraulically powered mixer tilt function, which allows the user to easily mix a batch as small as 200 lb (90.7 kg)—the smallest in the industry—to finish the job. The tilt also allows for fast cleanup.

Blastcrete can customize the 2200 Pan Mixer to fit any voltage and hertz requirements, including those outside of the United States.

For more information, contact Blastcrete Equipment Company, 2000 Cobb Ave, Anniston, AL 36202; telephone: 800-235-4867; fax: 256-236-9824; e-mail: info@blastcrete.com; website: **www.blastcrete.com**.

Putzmeister America, Inc., Introduces Upgrades to Thom-Katt® Line

Putzmeister America, Inc., has announced significant upgrades to its Thom-Katt® Trailer Pump line. The TK 40, TK 50, TK 60 HP, and TK 70 are the first models to feature a relocated fuel tank and new control box with display. The fuel tank relocation will be featured on the single and tandem axle units and will allow for increased ground clearance. The new TKs will be able to go where previous models could not, allowing for better access over rugged or uneven terrain.

The development of the new control box will provide for a more active presentation of pump information, diagnostics, and an emergency run mode. This feature allows the operators to make sure their pumps are operating at peak performance; and should a problem arise, the control box will minimize downtime. The new control box is also time-tested and present on current production models delivered from both Putzmeister Germany and Putzmeister Brazil.

Putzmeister's big boom pump expertise gives you powerful performance and rugged reliability in our Thom-Katt Trailer pumps. Ideal for pumping a variety of materials, Thom Katts can handle the harshest mixtures and tackle several difficult applications. Easy to operate and inexpensive to maintain, they set up faster, pump smoother, and are easy to clean. They are ideal for wet-process shotcrete across a wide range of applications, including refractory, underground, and civil projects.

Blastcrete Equipment Company's 2200 Pan Mixer

Putzmeister Thom-Katt Pump

The Thom-Katt S-Valve lets you reverse the stroke to relieve pressure when pumping difficult low-slump or fiber mixtures. The material cylinders and variable, smooth hydraulics allow precise control at low output for specialized applications. You can maintain much of the output pressure when reducing to smaller-diameter conveying lines—something larger cylinder concrete pumps cannot do.

Cemen Tech Introduces Next-Generation Volumetric Mixer at World of Concrete

CEMENTECH

Cemen Tech, a leader in the volumetric mixing industry, announced the prerelease of their new C860 volumetric mixers. The product was unveiled at World of Concrete 2015 in Las Vegas, NV.

The new model has many new features not previously available on Cemen Tech mixers. "We are pleased to offer our customers a new design that will make the operation easier and allow their drivers to pour concrete in a more efficient way," said Mark Rinehart, Director of Sales and Marketing for Cemen Tech.

The C860 features a new electronic control panel. The panel will allow those in the field to track the exact flow of admixtures and water electronically. All of the information required will be displayed on digital readouts and show the operator exactly the total number of yards produced during each placement. All of the technology used has been tested for over 30 years in the automotive and construction industries.

New design built from customer feedback and state-of-the-art electronic technology

One significant introduction is the addition of a GPS Tracking Solution. The system will allow tracking of the mixer's location and will alert managers when and where a mixer stops, as well as how many times the mixer runs each day. In the coming months, this system will also allow a person to send mixture designs to the mixer and control their unit from the comfort of their office.

"We have listened to our customers and are expanding our culture of innovation at Cemen Tech. We are excited about the release of C860 and gaining some more feedback from customers at the show," said Rinehart.

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: *I recently hired a pool contractor to build a residential pool. The contractor has been in business for more than 30 years and has a great reputation. The progress so far is that the pool has been installed using shotcrete. The shotcrete has been curing for the last 9 days. Within the last 9 days, it has rained heavily twice. On the second rainy day, immediately after the rain finished, I walked outside to see the amount of water that had collected inside the pool. I noticed that the water was muddy looking. Upon closer inspection, as the rest of the pool was dry, except for the deep end, there were two trails of water coming from the shallow end and running into the pool of water in the deep end.*

After getting down into the pool, I noticed that these trails of water were from water bubbling up through the shotcrete floor on the slope closer to the shallow end. The bubbling was like a small stream of water coming up out of the shotcrete in two places. I suppose it is from the hydrostatic pressure from the groundwater under the concrete? My question is should this be concerning? The plaster has not been installed. How should these holes be filled? The holes certainly do not look like they were intentional, as you can't really even see them, except for the water coming out of them. Is there a problem with the shotcrete installation? Does this mean that my pool will leak when it is filled with water? I would image that if water can come up through the shotcrete, the water can also go down through the shotcrete, resulting in erosion of the soil under the pool? Before the shotcrete was installed, there was no groundwater present and the dirt was dry.

Answer: It is difficult to make an assessment of a situation like this with a few photos and the description given. Based on your statement that the contractor has an excellent 30-year reputation, we'd suggest you discuss these concerns with the contractor. If his response does not give you a full explanation, we suggest you engage an independent professional familiar with shotcrete installations and swimming pools to give you an opinion. You can use ASA's Buyers Guide at **www.shotcrete.org** to find a consultant.

There certainly is reason to question the quality of the installation based on the description. However, it is not unusual for the pool shell contractor to leave a temporary opening in the shell to relive potential groundwater pressure and prevent floating of the empty pool shell. These holes are, or should be done, in a professional manner to allow complete watertight sealing when filled. In some cases, the openings may include a pressure relief valve.

Question: *We are proposing a vertical support of excavation structure using reinforced shotcrete to retain a 10 ft (3 m) high sandy soil. What are the design criteria to choose the reinforcement and the thickness of the shotcrete? Also, what is the minimum reinforcement and shotcrete thickness you would recommend?*

Answer: The shoring design should be done by a competent licensed professional engineer who specializes in earth retention systems. This is not a question that can properly be answered by ASA. You can search for such a professional in our Buyers Guide section of the ASA website (**www.shotcrete.org**). Another resource is the FHWA Manual for Design and Construction of Soil Nail Walls.

Question: *I am designing the resurfacing of the downstream face of a concrete gravity/mass concrete dam. I am calling for the addition of 9 in. (229 mm) of new concrete, reinforced with a grid of reinforcing bar, and anchored with dowels into the dam. I have specified wet-process shotcrete based on conventional knowledge (and Army Corps Engineering Manual EM 1110-2-2005) that wet-process shotcrete can be air-entrained and therefore provide better resistance to freezing-and-thawing damage, which is a concern for this application on a dam in New England. Contractors are requesting substitution of wet-process for dry-process due to the difficult site conditions; that is, working on a near-vertical surface over water with long distances (500 to 700 ft [152 to 213 m]) to pump the wet-mix shotcrete. My concern with dry-process shotcrete, in addition to no air entrainment and poor freezing-and-thawing resistance, is the low permeability of dry-process shotcrete. My concern is that a low/nonpermeable covering on the downstream face of the dam will trap the moisture that permeates* *through the dam from the head pond and either the static head pressure (from the head pond) or repetitive freezing and thawing of the trapped moisture will deteriorate the existing and/or new concrete and/or pop the new shotcrete off the dam. So my questions include:*

1. *Is air entrainment of dry-process shotcrete a proven and dependable process that will provide comparable resistance to freeze-thaw to that of wet-process shotcrete, as suggested by J. F. Dufour in* Shotcrete*, Fall 2008 issue?*
2. *What is the permeability/hydraulic conductivity of both wet- and dry-process shotcrete? Are there published numbers or ranges that can be used to compare the two methods to each other, and to traditional cast-in-place concrete?*
3. *What admixtures, if any, do you recommend to 1) entrain air; and 2) increase permeability in dry-process shotcrete?*

Answer: The downstream face of the dam could be relined with either wet-mix or dry-mix shotcrete. Both methods have been successfully used for this purpose on a number of dams and marine structures in North America and elsewhere. See for example the references that follow.[1-4] However, from a productivity perspective, wet-mix shotcrete is usually the preferred process, as it can be applied at about four times more volume per hour as compared to dry-mix shotcrete. Also, there is less rebound in wet-mix shotcrete.

In response to your specific questions, we comment as follows:

1. With the addition of an air-entraining admixture to dry-mix shotcrete (typically added as a dry-powdered admixture during batching in dry-bagged premix shotcrete, or sometimes as a liquid added to the mix water added at the shotcrete nozzle), the dry-mix shotcrete can develop an air voids system which provides good freezing-and-thawing durability.[5-7]
2. Research studies currently being conducted by LZhang Consulting & Testing in Canada show that the values of boiled absorption and volume of permeable voids (as measured in the ASTM C642 test), for cast concretes and wet-mix shotcretes made with the same cementing materials and aggregates and the same water/cementing materials ratio are quite similar. Values tend to be slightly lower in well-applied dry-mix shotcrete.
3. With respect to air-entraining admixtures for dry-mix shotcrete, contact the major chemical admixture supply companies to get recommendations for brand name products and recommended dosage rates.

In summary, air-entrained dry-mix shotcretes with good freezing-and-thawing durability are routinely used with good results in aggressive freezing-and-thawing exposure environments.[6,7] Dry-mix shotcretes have a long history of successful performance on the downstream face of concrete dams.[1,2] Wet-mix air-entrained shotcretes have been successfully used to resurface both the upstream and downstream faces of concrete dams and marine structures. With proper design of anchorage systems tying the shotcrete facing system back into the substrate concrete at depth, many decades of satisfactory performance have been demonstrated, even if the substrate concrete continues to experience frost action.[2-4,8]

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8. Forrest, M.P.; Morgan, D.R.; Obermeyer, J.R.; Parker, P.L.; and LaMoreaux, D.D., "Seismic Retrofit of Littlerock Dam," *Concrete International*, V. 18, No. 3, Mar. 1996, pp. 24-29.

Note: References 1, 3, 5, and 8 can be found in the book *Shotcrete, A Compilation of Papers*, by D.R. Morgan, published by the American Shotcrete Association, 2008, 424 pp.

Question: *Is it possible to apply shotcrete on glass? Can shotcrete or concrete bond with glass? If it is an issue due to the smooth surface properties of glass, will sandblasting help?*

Answer: We are not aware of any specific applications of shotcrete to glass. The glass would have to be tough or strong enough to withstand the sprayed application. We have seen shotcrete stick to smooth surfaces like glass and glossy paint, but have not seen any data on the bond. In general terms, better bond is achieved with roughened surfaces so sandblasting the glass would likely improve the bond.

Question: *There is a pre-stabilized steep slope (nailing is used along with shotcrete). The client wishes to benefit from the maximum achievable area in plan and is asking for excavation of the stabilized slope to shift back the wall face around a few meters.*

The new stabilization plan shall include a safe gradual excavation of the existing wall from top to bottom along with the destruction of the existing shotcrete face, reinforcement, and the installed nails. What is the most common destruction method for the existing shotcrete? At the same time, I think pulling out the nails using hydraulic jacks would be applicable.

Answer: The existing shotcrete can be removed by many methods, such as using a Hoe-Ram. The existing soil nails could be removed as suggested or left in place and trimmed back to some distance behind the new plane. We would assume that this work would be done from the top down installing new soil nails and shotcrete facing in lifts of approximately 4 to 5 ft (1.2 to 1.5 m).

Question: *My question is not directly on shotcrete/gunite, but a similar material—cementitious fireproofing material: a mixture of portland cement, vermiculite, and other additives, sprayed on to steel structures like a shotcrete. Because there is not much published information/data on this product, I am trying to find my answers based on shotcrete:*

1. *How do you check the compressive strength of an applied shotcrete? I know typically it is tested from test cubes casted at the time of application. The test cube may be used when testing for compressive strength, and one makes only one or two test cubes. If you have a doubt on applied shotcrete (that is, the mixture including water, prior to application), how can one check if everything is correct? Alternatively, if the cubes were not taken, is there any other testing method to check for compressive strength of the material installed?*
2. *What other inspections/tests are done during spraying or after installation on shotcrete to make sure that it is installed properly?*

Answer: We do not have any direct input on cementitious fireproofing, as it is likely applied at much lower velocities with lower impact forces than shotcrete. Shotcrete is generally tested by cores taken from shotcreted test panels (ASTM C1140/C1140M), but according to ASTM, can also be established from sawed cubes. If trying to establish compressive strengths from in-place shotcreted materials, ASTM C1604/C1604M would be applicable.

Question: *We are considering sealing off the openings of some existing water tunnels by constructing reinforced concrete walls within the openings. One wall, for instance, is 9.25 ft wide by 12 ft high (3 x 4 m) and is to be 22 in. (559 mm) thick. Other walls will be in the range of 18 to 26 in. (457 to 660 mm) thick. What are the limits as to the maximum thickness/size wall that shotcrete can be used to construct? Also, I noticed that in the latest revision of ACI 506R-05 that the previous recommended limits on the reinforcing bar size have been removed. I believe in the past, the reinforcing bars were limited to the smaller-size bars to reduce the development of sand pockets behind the bars. Is there a recommended limit on the size bars that can be used? Perhaps it was in the ACI standard but I just overlooked it.*

Answer: Experienced shotcrete contractors with qualified crews have often shot structural concrete sections 24 to 30 in. (610 to 762 mm) thick with reinforcing bars up to No. 11 in size. There is no real limit to how thick you can build a shotcrete "wall." Though earlier versions of ACI 506R, "Guide to Shotcrete," did recommend limiting reinforcing bars sizes, modern equipment, concrete mixtures, and shooting techniques have proven that large-diameter steel reinforcing bars can be properly encased on a routine basis by experienced shotcrete crews. Thus, ACI 506R was updated to reflect the successful industry practice.

Question: *We have a school project in California. It is for a structure with shotcrete walls and a shotcrete dome roof shot with an inflatable form. There is disagreement on the nozzlemen qualification panels. One group says that a panel should be shot for each nozzleman for each position (three panels: one vertical, and two for different slopes of the dome) in a single layer with the most congested reinforcing bar in any single layer to simulate job conditions. A second group maintains that the same three panels should be shot, but they should be built up over a period of 6 days in gradual layers to represent the layering of the actual shooting.*

I think that the first group is correct and complies with the intent of ACI 506. Shooting one-layer panels with the most congested reinforcing bar to be placed in any one layer would best simulate the job placement conditions. I don't see any added advantage in shooting qualification panels over a period of days in layers and seems to be reading too much into "simulating" jobsite conditions.

Answer: In construction of shotcrete dome roofs with inflatable forms, the structural thickness of the dome is built out in layers to prevent overloading the support offered by the inflatable form and foam. Thus, your nozzleman qualification panels should be representative of the dome construction methods. This would include shooting orientation (vertical and varying slopes), shooting procedures (layers), and with the most congested reinforcing. When shotcrete is applied in layers, all you need to do is wait for the first layer to stiffen sufficiently (usually called initial set), before applying the next layer. It is not necessary to wait for days before applying the next lift.

Question: *I've been testing shotcrete cores for compression strength according to ACI 506, ASTM C1604, and ASTM C1385. The only thing that we have been doing out of specifications is the panel. Our panels are 18 x 18 in. (457 x 457 mm). We have been coring at the center of the panel 2 days after it has been cast. We test these cores at 7 and 28 days, and the strength of cores reflects passing at 7 days but failing at 28 days.*

Can you please tell me what could be the cause of this?

Answer: ASTM C1140/C1140M-11, "Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels," is the appropriate ASTM standard for producing and coring test panels. ASTM C1140 specifies panel size as a minimum of 24 x 24 in. (610 x 610 mm) with a minimum 3.5 in. (89 mm) depth. Without more information on the materials used in the shotcrete and the type of shotcrete, it is impossible to identify what may be causing the lower compressive strength tests.

The compressive strength should increase between 7 and 28 days on a curve equivalent to cast concrete. Strength degradation between 7 and 28 days may be a result of poor shotcrete application or problems with coring or curing of the samples.

Question: *I am specifying shotcrete to lower a draft tube roof in a dam. I like the bond characteristics shotcrete provides over traditional concrete for this application. I have two questions I am looking at resolving in the design process. The amount of shotcrete could be approximated as a triangular wedge of 6.5 ft deep by 30 ft long and 34 ft wide (2 x 9 x 10 m). The concrete will be roughed and cleaned prior to applying the shotcrete and in good condition.*

1. *Reference ACI 506R-05 Section 5.5, "Anchors," indicates that overhead surfaces have anchor at 18 in. (457 mm) on center (OC)-both ways. For the design loads, I am able to space anchors at 3.5 ft (1 m) distances and not approach any loading issue. For most of the design, the dead weight of the shotcrete is the driving factor. I intend to have reinforcing bar (or wire reinforcement [WRI]) next to the roughed original concrete surface. I will require some small anchors between the primer anchors to stiffen up the reinforcement (as required). Do you know what the driving factor is behind the 18 in. (457 mm) spacing for anchors for overhead application? I would prefer not having to install so many anchors, and can see installation of that quantity of anchor hanging down from the roof up to 5 ft (1.5 m) long causing issue with applying shotcrete. I have been researching tunnel lining and from all the photos I have seen, they did not follow that guidance.*
2. *Temperature and shrinkage issues: The best criteria on designing for temperature and shrinkages has been from ACI 318 for slab design minimum reinforcement ratio and ACI 350-06, Table 7.12.2.1, minimum shrinkage and temperature refinement for various spans greater than ACI 318 provides. The temperature and shrinkage reinforcement is by far governing the amount of steel required in the shotcrete.*

   I am looking to specify steel fiber reinforcement or have WRI wire reinforced with every layer of shotcrete to help with shrinkage issue. If I use WRI wire, would I need the anchor at 18 in. (457 mm) spacing for each layer?

I also have a concern because the geometry varies from 6.5 ft (2 m) thick down to 2 in. (51 mm) thick over 30 ft (9 m), which will require terminating WRI wire as the material thins. Do you know if at this termination there will be cracking issues from discontinuities in the reinforcement?

The other item I am contemplating is to install construction joints for varying thicknesses to help reduce the shrinkage stresses, such as 2 to 12 in. (51 to 305 mm) and 12 to 30 in. (305 to 762 mm) and 30 in. to 6.5 ft (762 mm to 2 m). This is not the most desirable, but is doable.

Answer: This is a great application for shotcrete. As you've indicated, proper surface preparation of the substrate is key to getting a durable shotcreted section.

1. ACI 506R-05 does provide guidance for most overhead applications using a maximum recommended spacing of 18 in. (457 mm) OC. This comes from the need to provide a reasonable value for most types of overhead work. However, ACI 506R does provide "If special conditions exist, the design of the anchor spacing and size should be checked for sufficiency in pullout and shear." Thus, if the anchors are designed by an experienced engineer to accept the expected loads, the spacing can be determined by the designer, as long as the supported reinforcing is stiff enough to not vibrate when shotcreted. Many underground applications are designed to use larger anchors at a greater spacing.
2. The ACI 318 temperature and shrinkage requirements allow wider crack widths in structural sections than ACI 350. ACI 350 requires more reinforcing to help control crack widths and make the structures as liquid-tight as possible. Thus, if your roof section is exposed to water, the ACI 350 levels of temperature and shrinkage steel would be advisable.

   The spacing of the anchors wouldn't normally be influenced by the use of WRI wire or fiber, unless that was considered by the designer in the ability of the sections to carry stresses between the anchors. However, use of steel fibers in the mixture at any significant dosage is not compatible with encapsulation of reinforcing bars or mesh. The 18 in. (457 mm) spacing is a "rule of thumb"; the intent is to have sufficient anchors to ensure that the reinforcing bar or mesh is rigid and will not vibrate during the shotcrete placement.

If there is a termination of the temperature and shrinkage reinforcement in sections experiencing internal tensile stresses due to shrinkage or temperature, the section would be more prone to cracking at the point the reinforcement is terminated. However, geometry of the section can also contribute to the cracking potential.

Construction joints in shotcrete do not create planes of weakness, but act as monolithic concrete, because shotcrete has an excellent bond to previously shot sections. If you want to design to accommodate shrinkage and temperature volume changes in the concrete, you should provide movement joints (contraction or expansion).

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