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shotcrete MAGAZINE

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shotcrete MAGAZINE

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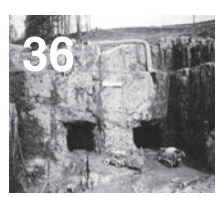
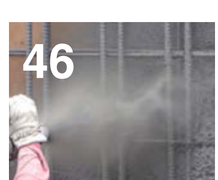
FEATURES





Shotcrete is a quarterly publication of the American Shotcrete Association. For information about this publication or about membership of the American Shotcrete Association, please contact ASA Headquarters at:

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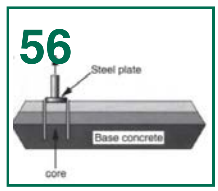
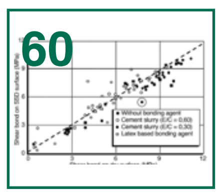
Editor's Note: Shotcrete is a placement method for concrete. However, for the sake of readability, the word "shotcrete" is often used either to identify the shotcrete process (method of placement) or the shotcrete mixture (product materials).





DEPARTMENTS

Collage of past Shotcrete magazine issues

As a commemorative issue, we will not be including some of our normal columns including:

- Association News
- Industry News
- New Products and Processes
- FAQs
- Sustaining and Corporate Member Profiles
- New Members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The Power of Mentorship

By Frank Townsend

We are a growing association, and shotcrete is expanding worldwide as a best practice for placing concrete. With this growth, we need to harness and develop new members who understand and can emulate the principles of quality shotcrete placement. For those involved in ASA, you know I am a people person, and mentorship and education are near and dear to me. ASA is laying out a new strategic plan with education and mentorship as crucial factors for our success. It is truly critical to our Association's retention and the satisfaction of our new members. We support company development and progression through our qualified contractor program and nozzlemen education sessions. We also need to strive to recruit the next generation. Involvement in undergraduate mentorship builds talent pipelines and provides access to students often excluded from traditional recruiting. We will make a push to educate at universities and colleges nationwide and eventually internationally. Likewise, younger companies or those growing their self-performing shotcrete arm, could also benefit from the experiences of veteran members. A mentorship program will be rolled out to help us grow.

Building a rapport between mentor/mentee is what makes mentoring genuinely transformative. This entails mutual trust and respect, a shared understanding of each other's values and perspectives, and strong communication. The quality of this connection is critical to retaining and growing our Association.

Mentorship helps us connect more deeply with motivations and values. Aligning these two will make us all stronger. With COVID, loneliness is a common feeling. We are not alone; we have a tremendous and growing association, and the mentorship program will help new companies get to know the Association better, make introductions, and get more people involved. It also forms friendships that span the Association, blending professional and personal worlds. Acknowledging how much our personal and professional lives intersect is a powerful basis for any mentoring relationship.

We will provide a clear sense of purpose in the mentor/mentee relationship to create excitement and momentum, solidifying the relationship and helping all reach their goals. The goal is not just to talk about each other's goals but to work on them together. Embracing the power of sharing, mentors will not always be driving the sharing; we will also put mentees in the driver's seat so mentors' perspectives from both sides could be shared and contribute to mutual growth.

In this time of change, professional disruption, loneliness, and expansion, mentorships can anchor us. This connection and role, coupled with a strong rapport and clarity of purpose, are critical to supporting our association through growth and turmoil, and they will strengthen relationships. Mentoring makes better leaders, developing skills to build rapport, listening to understand, and giving to receive. For leaders who feel that mentoring is one more thing they can't focus on right now, I encourage you to see this powerful tool as something that can liberate you and empower the association to support one another—and I hope you find purpose in doing so.

asa Sustaining Corporate Members

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

Geo Craft Builders
www.geocraftbuilders.com

CanCrete Equipment Ltd.
www.cancrete.ca

Curtis Concrete Pumping
www.curtisconcretepumping.com

Dees-Hennessey, Inc.
www.deeshenn.com

Maple Site Solutions
www.maplesitesolutions.ca/

Consolidated Shotcrete Inc.
www.consolidatedshotcrete.ca

REED Shotcrete Equipment
www.reedpumps.com

Coastal Gunite Construction Company
www.coastalgunite.com

Superior Gunite
www.shotcrete.com

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www.edencrete.com

Geo-Rope Ltd. (Canada)
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Construction Forms
www.ConForms.com

STS Shotcrete

MAPEI Underground Technology Team
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Cost of Wisconsin, Inc.
www.costofwisconsin.com

The Quikrete Companies
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Baystate Shotcrete, LLC
www.baystateshotcrete.com

Lanford Brothers Company, Inc.
www.lanfordbrothers.com

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

Master Builders
www.master-builders-solutions.com

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

Sika STM - Shotcrete, Tunneling & Mining (USA)
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ASA is here for you. Are you here for ASA?

By Jason Myers

As we see new work styles of a post-COVID world emerge and re-engagement in social activities, it is interesting to watch how people spend their time and efforts. I am involved in several associations and see a similar pattern emerging within all associations. The involved parties are still involved, the non-involved are still missing, but I now see a middle group, the "partially involved." Those who were once very involved seem to be more careful now with their time and efforts. The most successful post-COVID groups are those where people see a clear benefit in being involved. I submit, ASA is one of those organizations worthy of investing your time and effort.

No matter which side of the government aisle that you sit on, we can all agree that we feel hopeless with the government and the laws that are being passed these days. I even hear some of these same complaints regarding some of the guidelines and directions folks see in the shotcrete industry. However, one common thread is that those complaining are also the ones that are not informed or involved. Unlike government, you can have a say and an understanding of the shotcrete rules that govern our industry. At ASA Committee Meetings and Conventions, shotcrete topics are deeply discussed and debated. I know of several instances where people have used these events as a sounding board for industry trends and discussion. For example, the last ASA Shotcrete Convention had a great group discussion about the use of Remotely Manipulated Nozzles for shotcrete and how the training and certification of this style of shotcrete could proceed. At every level of ASA, there are active members of ACI committees that write and edit future ACI documents, standards used in our industry. Involvement with ASA members allow for direct contact and input regarding improvements to ACI documents. At least once a month, I receive a phone call or have a discussion with an engineer about an issue with shotcrete, and they often quote what they believe the shotcrete documents state. Most often, these discussions revolve around wrong interpretations or outdated information from previous documents from multiple iterations and decades ago. By being involved and understanding the rationale behind the wording in the documents, you gain a more comprehensive understanding of them. If you want to remain in the "partially involved group" and state what you think the shotcrete documents might have stated generations ago, that's your choice. The involved engages with the shotcrete documents and the people who write them, thus are better informed and gain a competitive advantage.

One complaint I've heard (from the less involved) is that they do not see any direct sales from their ASA membership. As a shotcrete contractor, I cannot think of any direct projects I have picked up by sitting down with somebody at an ASA meeting and working out a project with them. However, there is not a week that goes by that I do not use the knowledge that I have picked up from fellow ASA members, reached out to other members to glean from their experience, or utilized the great resource we have in the ASA staff, to make my projects run smoother and more efficiently.

If I have a supply need, I will always turn to an ASA supplier that I know will help with the issues I am facing.

ASA MEMBERSHIP COMMITTEE

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Kevin Robertson, Secretary | Sika STM- Shotcrete, Tunneling, & Mining (USA)

Patrick Bridger | Sika STM- Shotcrete, Tunneling, & Mining (USA)
Cathy Burkert | American Concrete Restorations Inc
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Raymond Schallom | RCS Consulting & Construction Co Inc
Ted Sofis | Sofis Company Inc
Dennis Bittner | The Quikrete Companies
Marcus von der Hofen | Coastal Gunite Construction Company

These fellow ASA members are not just another phone number but friends I have shared a beer with and broken bread with. They have fought the same battles that I am fighting, and I would bet they have experienced the issues that I am about to encounter. The "partially involved" don't experience these benefits. They might be looking only at the direct sale, but the involved person is the one who listens to the experience of others, learns the lessons of fellow shotcrete contractors, and applies those lessons to getting the next project or making the project that you have even more successful.

Another complaint and uncertainty that we all share is a concern about the future. Our current ASA President is emphasizing an important aspect concerning future growth, and that is shotcrete education, specifically in our colleges and universities. We all agree that construction is a small word, and the shotcrete industry is even tighter. The construction managers and civil engineering students of today will be our employees and project engineers of tomorrow. Shotcrete needs to be part of their education. The "partially involved" might hope that a future employee, or project manager, knows how to spell shotcrete. The involved ASA member is and will continue to educate them. There are numerous students that I have helped educate on the importance of basic understanding of shotcrete and these are the people that I have hired and see on the jobsite on a regular basis. This education continues with the ACI certified nozzleman and certified shotcrete inspector programs. The involved ASA members are using these tools to educate the engineers and inspectors out in the field today so they can call out the items that need to be completed correctly, ensuring that all shotcrete projects are completed per plans and specifications. Instead of sitting around, complaining about the contractor who is cutting corners, doing an inferior job, and giving shotcrete a bad name, let's educate the inspectors to ensure projects are completed to the high standards that our work should be held accountable to, and give our industry that great name it deserves. This also applies to the ASA Contractor Qualification Program. This is a program that showcases shotcrete contractors who are willing to stand behind the work they completed and are willing to allow their peers to affirm the work that they do.

While many who read this article are from the involved group, and those "not-involved" never receive this magazine, I am writing this to the group in the middle. Like everything, you get what you put into it. The person that wants everything to come to them with minimal effort will continue to be disappointed, while the person who invests time and energy into an Association committed to your success, will never be disappointed. ASA has a lot to offer and is here for you. Are you willing to be involved and be there for ASA, taking advantage of the opportunities offered?

Help!

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

No this isn't a review of the 1965 Beatles album (though it was a good one). This issue is Part 2 of our two-part 25th Anniversary set of Shotcrete magazine recognizing many of the best articles we've printed over the years.

Over our two and a half decades as the American Shotcrete Association, we've made great strides. My Executive Director Update in the last issue (Q4 2022) detailed many of our accomplishments as an association.

The strength of our Association is our members who actively exemplify our vision:

"To expand and advance global utilization of the shotcrete process for concrete placement."

Together as members we have a greater impact on the industry than any single company can achieve. We have a core staff of three full-time employees. Though as staff we accomplish much in keeping ASA moving and growing, we need members to work together to support our mission:

"We do this by providing shotcrete leadership, knowledge, resources, qualification, certification, and education for the concrete industry."

We enjoy a high level of engagement with our Executive Committee, Board and Committee members and are indebted to them and their companies for the ongoing support of their time, energy and enthusiasm for the shotcrete industry. Our pool of ACI-approved shotcrete nozzleman certification examiners also help us to provide the best nozzleman certification program in the world. But what can you do to support ASA and advance the use of shotcrete?

- **Join ASA.** Our Association depends on the financial support of our members, our events and our programs. Your paid membership is the foundation that allows us to have staff and run our organization as a business. With growing member support since 1998, we have built a great association that is highly recognized as The Shotcrete Resource. Owners, engineers, contractors and specifiers look to ASA for guidance on all aspects of shotcrete. Your continued membership is essential to our Association moving forward in support of our vision.
- **Join one or more of our committees** then, actively participate. Our committees provide the horsepower to develop and maintain our programs, position statements, educational seminars, safety guidelines, and conventions. Our committees include Contractor Qualification, Education & Safety, Membership, Marketing, Pool and Recreational, Underground and Technical. Committee participation not only raises the stature and acceptance of shotcrete, but also gives you a great opportunity to network with others dedicated to advancing shotcrete.
- **Attend one of our annual conventions.** We meet once a year in late February or early March in a warmer part of the United States. Our convention venues are selected to provide a cozy environment – not too big, not too small – in a resort setting. We have a small, open exhibit hall with tabletop exhibits that also serves as our breakfast and lunch area. We also provide a diverse list of educational seminars that focus on the shotcrete industry – research, innovation, materials, equipment, applications and more. The big event at the convention is the annual Outstanding Shotcrete Project awards banquet, celebrating excellence in shotcrete placement internationally! Showcase your craftsmanship by entering your outstanding project this year. These projects help us all highlight shotcrete's possibilities to our clients and designers. Overall, the convention is designed to encourage the maximum opportunity to network, socialize, and learn from other leaders in the industry.
- **Submit a presentation for the annual convention.** We are always looking for speakers willing to share their knowledge and experience in shotcrete. We don't require a paper be prepared, but do certainly welcome articles for Shotcrete magazine after the convention wraps up. Talks are about 50 minutes long with audience Q&A encouraged.
- **Write for Shotcrete magazine.** We welcome articles of interest to the shotcrete industry. Our magazines are distributed internationally to members, and digital versions are always freely available on our website. Don't feel you need to have a fully polished article. A Word document that captures the essence of your topic with accompanying photos and captions is all we need. Our ASA staff has three levels of technical and editorial editing to put the final polish on your article. And we give you full credit with a bio and headshot. A great way to promote you, your company and the work you do in the shotcrete industry. It's an opportunity to give voice to your passion.

ASA Charter Members as of January 1999

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Robert E. Guarino
Warren Harrison
Allen Lobo
Imran N. Merchant
Wolf Michelson
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Bill Roberts

- **Coordinate a local or regional ASA educational seminar.** Corporate members can coordinate presentations of ASA educational seminars with owners, engineers, architects and other specifiers who need to learn about the shotcrete process. Our educational seminars include the one-hour Introduction to Shotcrete, and Shotcrete for Underground Construction. This is provided free of charge to groups of 5 or more owners and specifiers. We also can provide our full-day Shotcrete Inspector education. This in-depth seminar provides owners, engineers, general contractors, and inspectors shotcrete knowledge to recognize and appreciate quality shotcrete placement. This also helps our contractors better communicate the excellence of their work to their project owners and inspectors.
- **Promote ACI Shotcrete Nozzleman Certification.** Ultimately the shotcrete nozzleman is the final QC person that determines the quality of shotcrete placement. On-the-job learning is good and required to gain the work experience required for certification. But by completing the full-day ASA education on shotcrete basics, and then passing the ACI written and performance examinations, they can demonstrate an acknowledged level of shotcrete competency. ACI certification is recognized internationally and sets the standard in certification of individuals in the concrete industry.
- **Become an ASA Qualified Contractor.** Our ASA Contractor Qualification Program verifies a shotcrete contractor's qualifications through a rigorous review of the contractor's past work. The ASA qualification program

provides a distinct service to the industry by assuring owners, general contractors and specifiers that ASA Qualified Contractors have a proven record for the completion of successful shotcrete projects. As with ACI Nozzleman certification, ASA Contractor Qualification recognizes the shotcrete contractor has a level of commitment to doing quality shotcrete work.

- **Do a Quality Job!** Nothing brings the image of shotcrete down in the eyes of owners, designers, specifiers and general contractors than poorly shotcreted concrete. We at ASA strive to continually enhance the application, acceptance and recognition of quality shotcrete placement. You can lose your reputation in a heartbeat. It can take years or decades to gain back the trust and confidence in your work that you once enjoyed. This quote from John Ruskin always strikes home with me:

"Quality is never an accident. It is always the result of intelligent effort. There must be the will to produce a superior thing."

You'll find more information about all these aspects of ASA at our website, shotcrete.org. As we move forward towards our 30th anniversary, please consider what you can do to help support ASA and advance the shotcrete industry. If you have any questions or thoughts about how you can participate don't hesitate to contact me at Charles.Hanskat@Shotcrete.org.

FIRST ASA CERTIFIED NOZZLEMEN:

ASA initiated the first class of certified shotcrete nozzlemen in 1999, in Streetsboro, OH. ASA members designed the program and wrote the exam following ACI 506.3R-91 requirements. ASA then passed the program administration over to the American Concrete Institute's (ACI) C660 – Shotcrete Nozzleman Certification Committee. ACI then became the certificating body who administers the program, grandfathering in ASA's initial class of nozzlemen into the program. ASA continues to be the primary sponsoring group for the ACI Shotcrete Nozzleman Certification Program, both Wet-Mix & Dry-Mix; and more recently, the ACI Shotcrete Inspector Certification Program.

Kenneth Bradshaw
BEK. Inc.
Anchorage, Alaska

Darran Buxton
Topcor Services, Inc.
Baton Rouge, Louisiana

Eric Campbell
Schnabel Foundation Co.
Marietta, Georgia

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Greg Wurst
C-Tec, Inc.
York, Nebraska

Mark Wurst
C-Tec, Inc.
York, Nebraska

Tony Zeleneski
South Shore Gunite Pool & Spa, Inc.
Lowell, Massachusetts

CERTIFICATION EXAMINERS SELECTED

Following the initial ASA certification in September, the ASA Certification Board confirmed that the following persons are qualified to act as examiners for future certification programs:

Jean-Francois Dufour
Merlyn Isaak
Marc Jolin
Pierre Lacombe
Neil McAskill
Ray Schallom III
George Yoggy

In 1999 Denis Beaupre, of Laval University has been designated as the new chairman of the ASA Certification Board. The other members are: Steve Gentry, Baker Concrete Construction; Mark Jolin, Laval University; Ray Schallom III, RCS Consulting & Construction; Chris Zynda, Concrete Structures.


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REGIS


Qualifications of the Shotcrete Construction Team

By Charles Hanskat

Shotcreting is an efficient method for placing high-quality, durable concrete in a wide variety of concrete structures. Shotcrete has been successfully used in substantial number of projects for well over a century. As with cast-in-place concrete, the quality of the shotcrete placement is dependent on the quality of the materials, proper mixing and transport, substrate/subgrade preparation, the placing process, and protection until final strength is reached.

However, a comparison of the shotcrete process to the traditional "form and cast" process shows significant differences. Specifically, when using the shotcrete process:

- Formwork is eliminated or substantially reduced.
- It is necessary to identify the best shotcrete process (wet- or dry-mix) for the job.
- Special gunning equipment is required, including pumps, guns, hoses, nozzles, and admixture/water pumps.
- Knowledge is required to safely use and maintain the shotcrete equipment.
- A trained field crew that performs work totally unlike casting concrete in forms is required.
- Environmental conditions that are unsatisfactory for quality shotcreting must be identified.
- The nozzleman must be well-versed in shooting techniques, including proper air, water, and mix flow.
- The crew must be prepared to properly finish, protect, and cure freshly placed shotcrete.
- Knowledge of quality control procedures specific to shotcrete is required.

Based on these factors, it is apparent that a contractor offering to place quality shotcrete can only truly be considered a qualified shotcrete contractor if every member of the shotcrete construction team—from company management through the field team—has specific knowledge, equipment, training, and hands-on experience in the shotcrete process.

ACI 506R-05, "Guide to Shotcrete," is a great primer on shotcrete design and application. ACI Committee 506, Shotcreting, is currently working on revisions to the "Guide to Shotcrete"; in the latest drafts, the committee developed an expanded section covering shotcrete crew requirements. The following provisions are summarized to help establish field crew qualifications. The requirements for designating a contracting firm as a quality shotcrete contractor are then presented. A shotcrete team that meets or exceeds the presented crew and contractor requirements will be best qualified to provide a cost-effective, high-quality, and durable shotcrete application.

FIELD TEAM DUTIES AND QUALIFICATIONS

(based on input from ACI 506 Subcommittee developing updates to 506R, "Guide to Shotcrete")

COMPOSITION AND CREW DUTIES

The basic shotcrete crew may consist of a foreman, a nozzleman, a finisher or rodman, an assistant nozzleman, a wireman, a gun or pump operator, a mixer operator (if needed), and laborers.

Depending on the size and complexity of the project, one person may perform more than one operation. For example, the foreman could also function as the nozzleman; one person could perform as the rodman and finisher; an assistant can help the nozzleman by both pulling the hose and operating the air-lance/blowpipe; and, if necessary, the gun or pump operator and mixer functions could be combined and, with proper equipment, performed by one person. Larger, congested reinforced projects, on the other hand, may require more than one nozzleman and air-lance operator and several finishers. Where several crews are operating, a foreman, superintendent, and engineer may be required.

Shotcrete Foreman's Duties—The foreman plans, directs, organizes, and coordinates the work of each member of the shotcrete crew to obtain a safe and successful application. This includes ensuring the safety of the work area and following quality control procedures. The foreman is responsible for the inspection and maintenance of equipment, as well as ordering and expediting the delivery of materials. The foreman sets the pace of the work, maintains crew morale, ensures good housekeeping, and acts as liaison with the general supervisor or the owner's inspection team. The foreman is usually a veteran nozzleman, finisher/rodman, or pump/gun operator and should be able to fill any of the positions if required.

Nozzleman's Duties—The nozzleman is a key person in a shotcrete operation. He is responsible for applying the shotcrete and bringing it to required line and grade in a workman-like manner. The nozzleman's duties include coordinating the application with the foreman, finisher or rodman, and pump/gun operator. Before the shotcrete is installed, the nozzleman should ensure that all areas to

Fig. 1: Nozzleman with his air lance man and hose tender

Fig. 2: Nozzleman, air lance man, and finisher in the background

Fig. 3: Pump, nozzleman, and hose tenders

receive shotcrete are clean, sound, and free of loose material and that anchors, reinforcement, and ground wires are properly placed and spaced.

In the dry process, the nozzleman controls the water content for hydration and ensures that the operating air pressure is uniform and will provide high velocity at impact for good consolidation. In the wet process, the nozzleman controls the air that increases or decreases the velocity to ensure proper placement, which includes proper encasement of the reinforcement.

The nozzleman provides leadership and direction for the shotcrete crew, which aids in the task of shooting high-quality shotcrete. The nozzleman is usually an accomplished finisher or rodman and gunman/pump operator.

Wireman Duties—The wireman sets elevations and thicknesses for the shotcrete placement, which may include the top and face of the wall. Grades set by the wiremen are the lines the nozzleman and finishers will follow. The wireman may use many devices for setting grades, such as piano wire, fiberglass-metal rods, plastic pipe, and so on.

Finisher/Rodman's Duties—The finisher rods, or cuts, the freshly placed shotcrete surface, bringing it to line and grade before final finishing. The finisher also locates and removes sand pockets, sags, and sloughs and guides the nozzleman to low spots that require filling with additional shotcrete. Before the shotcrete is set, the finisher brooms and prepares the surface for final application.

Assistant Nozzleman's Duties (blowpipe/air lance control)—The assistant nozzleman helps the nozzleman by dragging the hose and performing other duties as directed by the nozzleman. The assistant nozzleman relays signals between the gunman/pump operators and may also relieve the nozzleman for short rest periods. The assistant nozzleman may operate the air-lance, if one is required, to keep the areas in advance of the shotcrete free of rebound and overspray. The assistant nozzleman may be a nozzleman trainee and place shotcrete under the direct supervision of a certified nozzleman.

Gunman's Duties (dry-mix)—The gunman provides a constant flow of properly mixed dry-mix material to the nozzleman. The gunman operates and maintains a clean gun and assists in ensuring quality control. The gunman should be particularly attentive to the needs of the nozzleman to ensure that the mixture is properly prepared. The gunman generally oversees, controls, and coordinates the material mixing and delivery operation.

Pump Operator's Duties (wet-mix)—The pump operator regulates the pump to uniformly deliver the wet-mix shotcrete at the required rate. The pump operator is responsible for cleaning and maintaining the material hose and pump. The pump operator coordinates the delivery of the shotcrete mix and monitors the water content by observing or testing the slump of the mixture. The pump operator may change the delivery rate of the transit and ready mix trucks, including staging the trucks at the pump. The pump operator is also responsible for all the safety concerns of the pump and delivery line.

Mixerman's Duties—The mixerman's duties include, where applicable, the proportioning and mixing of the shotcrete mixture materials and maintaining and cleaning the mixing equipment. For field mixing, the mixerman is responsible for storage, care, and accessibility of the materials. The mixerman makes sure that the mixture is free of contaminated materials and debris and that the aggregates have the proper moisture content. He ensures a constant flow of shotcrete materials but is also careful not to mix more material than can be used within the specified time limits. The mixerman supervises the laborers who are supplying and loading the mixer.

Hose Tender's Duties—The hose tender's duties include moving tools, equipment, hoses, scaffolding, and materials. Hose tenders clean work areas, remove rebound and overspray, and provide support for the shotcrete application.

Project Engineer, Project Manager, or Superintendent's Duties—On large or complicated projects, a project engineer, project manager, or superintendent may be advisable. A shotcrete contractor usually employs engineers, project managers, or superintendents who may not be assigned to a single project full time. The project engineer, project manager, or superintendent is responsible for the material selection, mixture proportioning, preconstruction testing, qualifications of the crew, equipment selection, project planning, scheduling, logistics, materials handling, quality control, sampling and testing coordination, and troubleshooting technical problems during construction.

CREW QUALIFICATIONS

General—The quality of a completed shotcrete application results from the combined skills and knowledge of the shotcrete crew. The foreman and crew should have performed satisfactory work in similar capacities for a specified period. The entire crew is responsible for the safety of each member on any particular project.

Shotcrete Foreman—The foreman commonly has proficiency in all crew positions and is in charge of the crew and the safety procedures. The foreman typically has at least 2 years of experience in the placement of shotcrete.

Nozzleman—The nozzleman should be ACI certified (refer to ACI CP-60, "Craftsman Workbook for ACI Certification of Shotcrete Nozzleman") and have completed at least one application as a nozzleman on a similar project for the shotcrete contractor. In congested reinforced projects, the nozzleman should also be able to demonstrate, by preconstruction testing, an ability to satisfactorily perform the required duties and to apply shotcrete as required by specifications.

Assistant Nozzleman/Nozzleman Trainee—The assistant nozzleman/trainee should have 6 months of experience in a variety of shotcrete field operations that may include finishing, gun or pump operation, blowpipe/air-lance control, and hose tending. The assistant should be able to demonstrate knowledge of proper shotcrete equipment setup (pump/gun, delivery hose, nozzle, and air/water supply). When shooting, the assistant must be under the direction of an ACI Certified Nozzleman.

Blowpipe/Air Lance Control—This person should have experience in finishing shotcrete and have proven successful manipulation of the blowpipe on previous jobs as directed by an ACI Certified Nozzleman, shotcrete foreman, or superintendent.

Wireman—The wireman should have at least 1 year of experience in setting grades on projects with shotcrete applications.

Rodman and Finisher—The rodman and finisher must have shotcrete experience and care must be taken not to create sags and loss of bond. Previous work experience that provided acceptable results should qualify him for this position.

Gunman or Pump Operator—The gunman or pump operator should be familiar with and able to operate the shotcrete delivery equipment, know the proper methods of material preparation and mixing, and be familiar with the chosen method of communication. The pump operator and gunman should preferably have at least 1 year of experience operating the intended equipment and be familiar with all manufacturers' safety guides and operations.

Mixerman—The mixerman should know and perform the proper methods of material preparation and mixing to consistently mix and maintain the required mixture proportions, including the proper water-to-cementitious content ratio (w/cm). The mixerman should have a minimum of 6 months running the specific (or similar) mixing equipment used on the project.

Project Engineer, Project Manager, or Superintendent—The project engineer, project manager, or superintendent should have at least 3 years of relevant field experience.

SHOTCRETE CONTRACTOR QUALIFICATIONS

The uniquely different needs of the shotcrete field crew and equipment, when compared to that for conventional cast-in-place concrete work, require the support, commitment, and positive attitude of the entire contracting organization for successful execution of quality shotcrete projects. Successful shotcrete projects demand full corporate support in:

1. Establishing and enforcing safety and quality control policies.
2. Purchasing and maintaining the proper equipment for each project's particular needs.
3. Committing to hire, train, and maintain the needed field personnel.
4. Handling the logistics of bidding, scheduling, and preconstruction requirements in an efficient manner.
5. Maintaining good client relationships, without which the shotcrete project may be less than successful.

The owner or specifier should always require an experienced and qualified shotcrete contractor team for executing quality shotcrete work. With this in mind, the following are suggested attributes for an owner or specifier to consider when selecting a qualified shotcrete contractor. By seeking out a contractor with the recommended qualifications below, the owner or specifier may rest assured that the entire shotcrete construction team—including a qualified contractor, ACI Certified Nozzleman, and experienced crew—has proven its ability to consistently place quality concrete by the shotcrete process.

Qualified contractors should have:

1. Five years of experience as a licensed contractor.
2. Five shotcrete projects of similar size, scope, and process (dry- or wet-mix) which were successfully completed within 5 years and have proper documentation, including full contact information for the owner/engineer/construction manager/general contractor, a project description, and the scope of work accomplished.
3. The ability to self-perform all shotcrete-related work and a minimum crew and staff listed as part of the company (either employees or substitutes with a work history under the current business name) consisting of the following minimum experienced field crew members:
   a. Shotcrete Foreman
   b. Nozzleman (at least one ACI Certified Nozzleman on the project)
   c. Dry-mix Gunman or Wet-Mix Pump Operator
   d. Assistant Nozzlemen/Nozzlemen Trainees (blowpipe/air lance controller)
   e. Finishers
   f. Mixerman
   g. Hose Tenders
4. Ownership of all necessary shotcrete equipment (pumps, guns, and hoses) to accomplish the job based on the specific project needs. The contractor must submit sizes and models of all shotcrete equipment to be used and should have a full equipment backup in case of equipment breakdown.
5. A certificate as a Business in Good Standing from the state that the company resides in.
6. A letter of bonding capacity from the bonding company or a letter of credit.
7. Company insurance in good standing that meets all state minimum requirements, including, but not limited to, general liability and workers' compensation.
8. ASA Sustaining or Corporate Membership.
9. Ability to demonstrate that members of the company construction support staff (for example, safety, general superintendent, project managers, and construction managers) have educational session credits through an industry-appropriate continuing education program specifically addressing shotcrete design, construction, or administration (ACI certifications; ASA education sessions [including ASA Onsite Seminars]; seminars; or trade shows, such as World of Concrete, ACI conventions, and ASA meetings).
10. An office or business base (with an address).
11. References (including those from the five projects in Item #2).
12. Affiliations.
13. Full disclosure of any criminal or fraudulent rulings for shotcrete work against former or current company owners in a 5-year period.

Summary

To consistently produce quality shotcrete work, the shotcrete contractor and key personnel all require proper qualifications through training in shotcrete materials, equipment, placement methods, curing, and protection to handle a particular project. It must be stressed that training in only one of these elements cannot guarantee success, and poor performance or lack of shotcrete knowledge by any member of the crew can cause a substandard finished product.

Simply specifying the use of an ACI Certified Nozzleman WILL NOT guarantee successful shotcrete placement on a project. The ACI Nozzleman Certification program was designed to establish that the tested nozzleman is capable of shooting at an "entry" level. The nozzleman receives his certificate for each process and orientation if he succeeds in the written and the performance exam. However, the performance exam is not representative of the shotcrete application experience needed to consistently and properly place shotcrete. The shotcrete construction market has a wide range of project needs from basic, lightly reinforced, thin shotcrete sections to complex and congested structural systems requiring substantially more experience and sophisticated techniques. The wide spectrum of construction practices, shotcrete processes, performance requirements, and geographic differences can impact shotcrete placement in many ways. No certification program can address all potential variables. The ACI Nozzleman Certification program simply verifies that the certified nozzleman has basic shotcrete knowledge and has adequately shot a shallow, flat, lightly reinforced test panel. This establishes that the nozzleman has the potential to do a satisfactory job, once the experience required for a specific type of project is gained.

Only by selecting a quality shotcrete construction team composed of a qualified shotcrete contractor, a trained and experienced crew (including an ACI Certified Nozzleman), and the proper equipment and materials can you be reasonably assured your shotcrete project will produce the high quality, durable concrete structures that shotcrete is capable of creating.

AUTHOR'S NOTE

The basic content of this paper was reviewed and updated by a select task group of ASA Board members with many decades of shotcrete contracting experience. The paper was submitted to the ASA Board of Directors (BOD) for consideration as an official ASA Position Paper at the Spring 2013 BOD meeting. After full Board review and approval, look for the official ASA Position Paper on our website www.shotcrete.org.

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

Shotcrete Contractor Qualification Evaluation Checklist	
	Five years of experience as a licensed contractor.
	Five shotcrete projects of similar size, scope, and shotcrete process (dry- or wet-mix), successfully completed in those 5 years with proper documentation
	Shotcrete Contractor self-performs all shotcrete-related work and has provided an experience listing of the minimum crew to be used on the project (refer to additional checklist for the Shotcrete Field Team Qualifications)
	Owns all necessary shotcrete specific equipment (pumps, guns, and hoses) to accomplish the job based on the specific project needs. Shotcrete Contractor has submitted sizes and models of all shotcrete equipment to be used—including full equipment backup in case of equipment breakdown
	Certificate as a Business in Good Standing or equivalent from the state that the company resides in
	Letter of bonding capacity from the bonding company or a letter of credit
	Company insurance in good standing and meeting all state minimum requirements. (including, but not limited to, general liability and workers' compensation)
	Contractor is a Corporate Member of the ASA
	Contractor documents that company construction support staff (for example, Safety, General Superintendent, Project Managers, and Construction Managers) have continuing educational session credits
	Physical office, shop, or other business address
	References (preferably including those from the five shotcrete projects of similar size, scope, and shotcrete process)
	Company Affiliations (for example, ASA, ACI, AGC, and ABC)
	Contractor has disclosed any criminal or fraudulent ruling for shotcrete work against former or current company owners in a 5-year period

Shotcrete Field Team Qualification Checklist	
	Shotcrete Contractor has submitted names, positions, and experience of field team members as required for the project and generally including: 1. Project Engineer, Project Manager, or Superintendent 2. Shotcrete Foreman 3. Nozzleman (at least one ACI Certified Nozzleman on the project) 4. Gun or Pump Operator 5. Assistant Nozzlemen/Nozzlemen Trainee(s) 6. Wireman 7. Blowpipe/Air Lance Controller 8. Rodman or Finishers 9. Mixerman 10. Hose Tenders
	Project Engineer, Project Manager, or Superintendent—minimum 3 years of relevant experience
	Shotcrete Foreman—minimum 2 years of shotcrete experience
	Nozzleman—holds current ACI Nozzleman Certification appropriate for the work and has completed at least one similar application as a nozzleman on a similar project for the Shotcrete Contractor
	Gunman or Pump Operator—should have at least 1 year of experience operating the intended equipment and be familiar with all manufacturers' safety guides and operations
	Assistant Nozzleman/Nozzleman Trainee—should have 6 months of experience in various shotcrete field operations that may include finishing, gun or pump operation, blowpipe/air lance control, and hose tending. When shooting, must be under the direction of an ACI Certified Nozzleman
	Wireman—should have a minimum of 1 year of experience in setting grades and profiles on shotcrete work
	Blowpipe/Air Lance Controller—should have experience in finishing shotcrete and have proven successful manipulation of the blowpipe on previous jobs as directed by an ACI Certified Nozzleman, Shotcrete Foreman, or Superintendent
	Rodman or Finisher—has proven successful shotcrete finishing on previous shotcrete projects
	Mixerman—should have a minimum of 6 months of experience running the specific (or similar) mixing equipment in use on the project

ACI Nozzleman Certification—Why, Who, When, and How

By Charles Hanskat

ASA is the largest ACI sponsoring group offering ACI Shotcrete Nozzleman Certification in the world. Since I came on board as the ASA Executive Director 3 years ago, the certification program has evolved and improved in many ways. Yet, as ACI readily admits, the nozzleman certification program is one of the most complicated certifications programs they offer. Although I was an ACI examiner for shotcrete certification several years before becoming ASA Executive Director, learning all the ins and outs of the program has been a distinct challenge. Fortunately, I've had our in-house expert on the certification process, Alice McComas, to help guide me along the way. In this article, I hope to translate some of the policy requirements into a more readable format, as well as give an insight into the finer details of the current ASA/ACI nozzleman session process and requirements.

ASA Holds Initial Shotcrete Nozzleman Certification

George Yoggy stands the field orientation for the first certification course

Streetsboro, Ohio, a small town just southeast of Cleveland, recently became the site for a landmark occasion in the shotcrete industry. For six days in September, 1999, the back lot of the Master Builders' manufacturing plant and a local hotel in Streetsboro became the venues for the first shotcrete nozzleman certification held by an industry association in North America.

The first three days were comprised of intensive training, peer-review, and curriculum development by a dedicated group of acknowledged industry experts. Working day and night, and even into the wee hours of the morning, they completed the necessary documentation, test procedures, and examination questions to enable the first class of nozzleman candidates to take a two-day instructional course and complete their certification examination on the last day. A total of 15 nozzlemen were enrolled, and all were certified in some or all of the configurations on which they were tested.

Neil McAskill (left) and Lars Balck collaborate on one portion of the training presentation

Personnel

Before the program was undertaken, an initial Certification Board was named to oversee this pilot offering. Chairing this first Board was Dr. D.R. "Rusty" Morgan of AGRA Earth and Environmental, Ltd. The other members were George Yoggy, Allentown Shotcrete Equipment Co; Lars Balck, The Crom Corporation; Marc Jolin, SEM Engineers; and Larry Totten, Johnson Western Gunite Company. These and several others were invited to participate in the planning sessions which were held from Sunday through Tuesday preceding the classes and certification testing. Joining Morgan, Yoggy, Balck, and Jolin were Neil McAskill, AGRA Earth and Environmental LTD; Ray Schallom, RCS Consulting and Construction, Inc.; Jean Francois Dufour, King Packaged Materials Co.; Pierre Lacombe, SEM Engineers; and Pat Bridger, Allentown Shotcrete Equipment. Observing for future program participation were Roland Heere, AGRA Earth and Enviromental LTD.; and Ray Bradshaw, BEK Inc.

Also participating in the planning sessions was Merle Isaak, Chairman of ACI Committee C 660-Shotcrete Nozzleman Certification, who acted as both contributor and observer to assure that the ASA program was developed in accordance with both current ACI documents and also with the plans for the future ACI Shotcrete Nozzleman Certification program.

Pierre LaCombe, Ken Bradshaw, Pat Bridger, and George Yoggy pore over slides for inclusion in the training program

Preparation

In addition to working diligently on the classroom presentation and the written exam, all these future trainers and examiners spent many hours in actual nozzling and also in observing and critiquing each other. A wide variety of equipment and materials was used in these sessions to assure that each person was familiar with all the situations on which the candidates would be tested. Both wet and dry mix shotcretes were used, as well as different combinations of nozzles and hose sizes.

Each afternoon, after the shooting sessions were over, work started again on the documentation portion of the program. The

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Shotcrete *magazine article from November 1999*

At ASA, we recognize the importance of nozzleman certification to the shotcrete industry, and strive to provide a consistent, high-quality, and relevant experience for the session hosts and the nozzlemen participants. In 2017, we conducted 78 sessions, with 260 new certifications, 139 recertifications of existing nozzlemen, and 77 nozzlemen-in-training (NIT). Those sessions were spread primarily across the United States and Canada, but also included a session in Australia.

Checking the ACI website shows we have a total of 1713 certified nozzlemen worldwide, so adding 337 is nearly a 20% gain. In a time where attracting young people to enter construction careers is an industry challenge, it is encouraging to see this kind growth, in what is admittedly a tough, physically demanding, and often dirty job.

Over the years, we've printed several articles about the ACI Nozzleman Certification. The first, in the November 1999 *Shotcrete* issue, "ASA Holds Initial Shotcrete Nozzlemen Certification," documented the first shotcrete nozzleman certification session.

This was a pilot run put together by a collection of ASA members with extensive shotcrete experience, and was the model for the formal ACI Nozzleman Certification program that followed, established in 2001. A Summer 2013 *Shotcrete* article by J. F. Dufour, Marc Jolin, and Randle Emmrich, "Shotcrete Nozzlemen: ASA Educates-ACI Certifies," presented the then-current policies of the ACI Shotcrete Nozzleman program and identified ASA's role as an ACI Sponsoring Group. That article also described the ASA full-day nozzleman education course for all nozzlemen seeking new certification. Another article in the Summer 2013 issue, "ACI Nozzleman Certification Sessions: What Not to Do," by Bill Drakeley, was directed to the potential ASA/ACI nozzleman session hosts. It covered the do's and don'ts, with a lot of great tips for a company hosting a session. You can find all these articles in our magazine archive (**www.shotcrete.org/ArchiveSearch**).

So where are we with the ASA/ACI Nozzleman Certification program today? To help explain our comprehensive, but complicated program, I'll break it into more manageable chunks: Why, Who, When, and How.

WHY

Before ACI Nozzleman Certification was available starting in 2001, specifiers were often hesitant to specify shotcrete because they were not familiar with the details required for quality shotcrete placement. Some had problems when they did try to allow shotcrete on a project, and an inexperienced contractor did a poor-quality job. ASA was formed in 1998 to help raise the visibility and quality of shotcrete in the concrete construction industry. Outreach seminars, trade shows, and active ACI committee involvement were ways we worked towards the goal, but we also saw that getting an ACI nozzleman certification in place would give us a tool for specifiers to more confidently start including shotcrete in their specifications.

ACI is an international organization that has produced codes and standards used by engineers and contractors globally for nearly a century. Their certification programs for individuals, such as Field Testing Technician, or Flatwork Finisher and Concrete Special Inspector, are internationally recognized and accepted as setting the standard for concrete-related certifications.

Thus, ASA identified the nozzleman certification process as a key to getting better specifier recognition of shotcrete. We also felt that by quantifying the experience, knowledge, and performance of a nozzleman, we could ultimately increase the quality of shotcrete placement. ASA members developed the initial program and pilot session along with ACI Committee C660, Shotcrete Nozzleman Certification, and then actively participated on Committee C660 to get the formal policy to match the needs of the industry.

That said, we firmly feel that simply specifying a certified nozzleman does not guarantee a properly executed shotcrete project. Yes, the nozzleman directly controls the actual placement of concrete and is a key member of the shotcrete team. However, true quality comes from a shotcrete contractor who gets the correct concrete mixture; provides proper, well-maintained equipment; has a trained crew, from the pump or gun operator through the finishers; and recognizes the importance of curing and protection of freshly shotcreted work.

The nozzleman certification is in many ways like a driver's license. You know how to drive a car, and the rules of the road, but you have not in any way experienced all the potential situations that may arise when driving. The nozzleman certification establishes you know the basics of shotcrete, can successfully pass a written exam to confirm that knowledge, and then prove to an examiner you can shoot a panel that has a few reinforcing bars. It doesn't mean you can successfully shoot a very thick section with congested reinforcing. It doesn't mean you can shoot around large embeds or in limited access areas. The ability to properly and consistently shoot more complicated work comes with experience. Often, an engineer on a complicated project will require the certified nozzleman to shoot a mockup panel to prove they have the ability to place quality shotcrete and fully encase the reinforcement.

Nozzleman certification also gives the nozzleman benefits. Through our ASA Education program, they learn more about the shotcrete process and the theory and practice for safety, selecting materials, equipment, placement, curing, and protection. It is also an achievement, a "status" level they've achieved as a shotcrete craftsman.

WHO

Nozzleman applicants must have verifiable work experience shooting shotcrete. This is not time preparing substrates, building forms, shoveling rebound, operating the pump or gun, finishing, or curing. This is time the nozzleman is on the nozzle and placing concrete. For those workers looking to become nozzlemen, operating the blowpipe (air lance) adjacent to a nozzleman can give good experience on identifying good placement techniques.

Full Nozzleman Certification

The full nozzleman certification is in the shotcrete process (dry- or wet-mix) and orientation (vertical or overhead), and requires a minimum of 500 hours of shooting overall, and at least 100 hours in the specific process and orientation being pursued. These shooting hours can be from any project before the certification. As an example, if a nozzleman has 500 hours in wet- and dry-mix and wants to be certified in both vertical and overhead for both processes, they would need to show at least 100 hours in each of the wet-mix vertical, wet-mix overhead, dry-mix vertical, and dry-mix overhead categories.

Nozzleman-in-Training (NIT)

In 2015, ACI Committee C660, which oversees the ACI Nozzleman program, added a new category of "Nozzleman-in-Training" to applicants seeking certification. The NIT requires a minimum of only 25 hours of shooting experience in the process being pursued for certification. The NIT is limited to certification in the vertical orientation in the process where they have documented their shooting hours. If a NIT wants to pursue both wet- and dry-mix, they would need to show 25 hours of shooting experience in each process.

The thought behind adding the NIT was to help answer the question, "How do I get my 500 hours of shooting experience?" The NIT program, with the ASA education and CP-60 Craftsmen Workbook, introduces the entry-level nozzleman to the basics of the shotcrete process that they may not get from just on-the-job shooting. The 25 hours gives a measure of confidence that the NIT had seen and could safely handle a shotcrete nozzle during placement.

The NIT must attend the full-day ASA Nozzleman Education class, take the ACI written exam on the process they are pursuing, and take the ACI performance exam. Upon successfully passing the exams, they will be given a NIT certification. The NIT then documents their shooting hours on a project-oriented weekly form after passing the exams. When they reach the minimum of 500 hours, their revised work experience is then reviewed by an ASA examiner for upgrade to a full nozzleman certification. Thus, the NIT is not a full nozzleman certification, but provides a clear path for those seeking the full certification.

We've also found the NIT program is popular with companies hosting sessions. It allows hosts to maximize the value of the sessions for new or recertifying nozzlemen by including the "up and coming" nozzlemen who look to full certification in the future.

Recertification

A certified nozzleman can recertify at any point in their 5-year certification period. If a nozzleman recertifies before his certification expires, their new certification extends from the time they took and passed the performance exam for the recertification. If the nozzleman's certification expires, they have 1 year from the expiration date to recertify under the same rules as a nozzleman in good standing.

The required work experience hours (shooting on the nozzle) for recertification are a little more complicated. The policy requires:

1. At least 1000 hours over the last two (2) years immediately prior to seeking recertification, with at least 200 hours in the process for which recertification is sought; or
2. At least 2500 hours over the last five (5) years immediately prior to seeking recertification, with at least 500 hours in the process for which certification is sought.

When a nozzleman recertifies by documenting their shooting hours and taking the performance exam, an expanded oral examination by the ACI examiner (usually about 20 to 30 minutes long) will be given to verify they have retained the basic knowledge about concrete and shotcrete in the written exam. They will not need to take the written exam.

Optionally, the nozzleman seeking recertification can elect to take a written exam instead of the oral exam, and will NOT have to document any hours. In effect, their minimum 500 verified shooting hours from the original certification are still valid. We find this is useful when a nozzleman advances to a supervisory position, and may not be shooting regularly, but still wants to maintain their certification status. This option is also available to nozzlemen seeking recertification whose certification expired for less than 1 year.

Session Hosts

Our certification sessions are normally "hosted" by a shotcrete company that has a number of nozzlemen needing certification. We refer to these as the "Hosts." We need a contact assigned from the Host to help the coordination of the session. The Host is fully responsible for providing a facility for the education if we have new nozzlemen certifications, and a quiet area for taking the written exam. The Host also needs to provide a site for shooting the shotcrete performance panels and all materials, equipment, and setup of panels for the performance exams.

Often, a Host will open their session to participants outside their company to help defray the cost of the overall session. ASA keeps a list of individuals or smaller companies who can't afford a session on their own. If a Host decides to accept outside participants, ASA will connect the two, and allow them to contact the Host directly for full information on the session. The Host is responsible for providing the outside participants a price, information on timing and location of the session, and collecting payment for their inclusion in the session. ASA looks to only the Host for full payment for all aspects of the session.

Occasionally, ASA has a Host conduct an "open session." This is a session where more than half the participants are not employed by the Host. To help assure the open session is well organized and can give the nozzlemen a good opportunity to demonstrate their skill, ASA staff will interview the Host on the specifics they intend to provide for the session, and make recommendations on any improvements that may be needed.

ASA/ACI Examiners

ASA has 16 ACI examiners who have been vetted by ACI Committee C660 to conduct the ACI shotcrete nozzleman certifications. Our examiners all have extensive experience in placing or evaluating shotcrete in field conditions. Examiners must undergo a training program that includes working with existing examiners on at least two sessions, plus taking the written exams for the process they are qualified to conduct. They are also reviewed and approved by ASA to professionally present the ASA nozzleman education program. We have four examiners in Canada, one in Mexico, and 11 in the United States. Our Mexican examiner is fluent in Spanish, and one of our Canadian examiners is fluent in French.

WHEN

When should you get your nozzlemen certified? Sooner than later. Getting your nozzlemen certified gives you as a shotcrete contractor the opportunity to show owners or specifiers, that you have made the commitment to pursue quality shotcrete work. A certified nozzleman does not assure the shotcrete project is executed properly, but it is certainly an important step in establishing your shotcrete credibility.

Bidding work that requires a certified nozzleman and waiting until the job is awarded to you is often too late. The fastest a session can be scheduled without a substantial rush fee is 3 weeks, and we prefer at least 4 weeks. We have ASA/ACI examiners spread across North America. However, this is not a full-time job for them, and on occasion, we run into scheduling conflicts that can make a quick session difficult or impossible to schedule on your timetable.

Our normal sessions are 3 days long, with 1 day for the ASA education, 1 day for taking the written exam and shooting the performance exam panel, and then on the third day, coring the panel for evaluation of the cores and quality of reinforcement encasement. If the session includes a larger group of nozzleman candidates where we'd need to shoot more than 14 performance panels, we will often require an additional day or provide a supplemental examiner to allow for the shooting and coring times. If a session runs into problems with weather, equipment failure, or material issues, the session Host can coordinate with the examiner to extend the session by a day.

We conduct sessions based on the session Host's schedule. When needed, our examiners can conduct portions of the sessions on weekend days to reduce the impact on your job schedule. You should plan on full days for the session. The education is a full day of content, and unless shooting and coring goes very smoothly, those two operations can easily extend to later in the afternoon.

HOW
Book a Session

First, contact us! E-mail to info@shotcrete.org, call us at (248) 848-3780, or go to our Education page on the ASA website (**www.shotcrete.org/Education**). After contacting us, our Program Coordinator, Alice McComas, will coordinate producing a quote for the session, assigning an examiner, collecting payment and the work experience forms before the session, and then verifying the paperwork from the examiner upon completion of the session.

Before you call or fill out the online request, you should have this information handy:

- The number of nozzlemen to be certified:
  - How many are full, new certifications?
  - How many are NITs?
  - How many are recertifications?
    - Do they have the required hours, or will they be taking the written exam?
- What are the processes (wet or dry) and orientations (vertical or overhead) to be shot?
- What time frame (days) are you thinking of holding the session?
- Will any of the nozzlemen need a Spanish version of the workbook or exam?
- Will any of the nozzlemen require oral administration of the written exam?
- Contact information for the individual assigned as the Host contact for the session.

We have many certification session resources on our Education web page, including:

- Typical timeline for Certification and or Education Session;
- ASA Certification and Education Fees Price List;
- ASA-Sponsored ACI Shotcrete Nozzleman Certification Policy for Hosts and Participants;
- Nozzleman-In-Training Program Overview;
- Nozzleman Work Experience Form for Certification;
- Nozzleman Work Experience Form for Nozzleman-in-Training (right click to save file);
- Test Panel Configuration for Shotcrete Nozzleman Certification;
- Certification User's Manual;
- Order the latest Annual Nozzleman Compilation;
- Certification/Education Session Quote Request Form (for both wet-mix and dry-mix);
- ACI Shotcrete Nozzleman and Nozzleman-in-Training Dry-Mix Program Description;
- ACI Shotcrete Nozzleman and Nozzleman-in-Training Wet-Mix Program Description; and
- ACI Shotcrete Nozzleman Certification Policy.

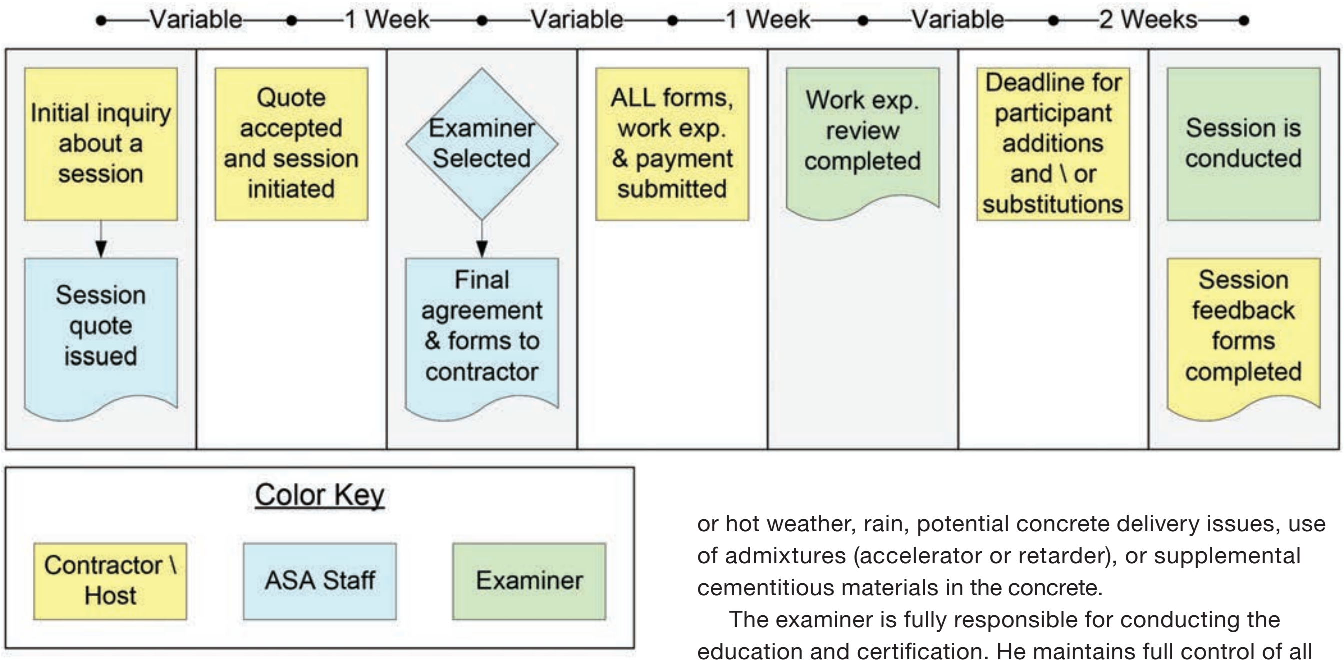
Our certification sessions are generally held at a Host Contractor site. The host location should provide a classroom (when there are new nozzlemen certifications) and panel-shooting facilities. Often, the session is at a company shop where there may be a training room and outside facilities for shooting the panels. However, we have conducted sessions on job sites or other facilities. I even did one on the owner's farm (complete with roosters and goats in the barn).

Unions can be Hosts for the sessions. However, ACI requires that the ACI certification cannot take place on union property. Thus, though the ASA day-long education can be presented at a union facility, the written and performance exams need to be conducted elsewhere. Often, we recommend the union look for a local shotcrete contractor and coordinate the session at their facilities, and with their equipment and proven materials.

When filling out the required work experience forms, we often see applicants correctly list the project, dates, employer, and contact, but in the "Wet or Dry Mix," and "Vertical or Overhead" fields list "Both." This is not acceptable, and requires staff or the ACI examiner to contact the host or nozzleman to get the breakdown of the hours shooting for each process and orientation. It is also important on the work experience to provide enough detail in the "Scope of Work" section so the examiner can establish the type of work (repair, soil nail, structural wall, and so on), the volume or area of concrete placed overall, and a range of thicknesses being shot on the project. We do check the shooting hours against the volume or area shot to confirm the stated numbers make sense from a practical field perspective.

Host the Session

As mentioned previously, we need confirmation of the session at least 3 weeks (and preferrably 4 weeks) before the session start date to allow assignment of an examiner, review of work experience forms, securing necessary exams from ACI, and arranging examiner travel. The following is a typical timeline for our session process.



ASA Certification Session Process and Timeline

Once the session is booked, we assign an examiner to the session. The examiner is responsible for reviewing the work experience forms and contacting the Host well before the session. This pre-session contact gives the Host an opportunity to ask questions about the required facilities, daily schedule, materials, shotcrete equipment, and setup. In the pre-session contact, the examiner can get details on the location (or locations—sometimes the classroom session is at a different facility from the shooting location), equipment and materials to be used, safety, and overall setup. There may also be discussions on provisions for cold or hot weather, rain, potential concrete delivery issues, use of admixtures (accelerator or retarder), or supplemental cementitious materials in the concrete.

Overhead standard setup—ACI Shotcrete Nozzleman Certification

The examiner is fully responsible for conducting the education and certification. He maintains full control of all exam materials, and conducts the session in a professional manner. With the years of field experience our examiners have, they usually establish a good relationship with the nozzlemen during the session, because most were nozzlemen at some point in their career and thus understand what a nozzleman must accomplish in the field. The examiner should not be there to promote any particular products, but present a neutral, unbiased viewpoint on proper shotcrete placement.

Written exams are all graded by ACI after they are returned to ACI headquarters by the Examiner. The performance exams are graded by the Examiner. The results of the performance exam (pass or fail) can be shared with the nozzlemen at the end of the session. Nozzlemen do not have to be present for the coring, but many examiners enjoy the opportunity to review the cores with the nozzlemen that shot them on the last day of the session.

The nozzlemen are informed of their certification status after all exams are returned for the session, and the written exams are graded by ACI. ACI can normally grade the exams and when they pass, post the nozzleman's certification on the certification website for verification (**www.concrete.org/certification/verifyacertification.aspx**) within 2 weeks after receipt. The nozzleman's printed credentials are mailed to the address given in the session. If the Host wants to have the credentials mailed to the company first, they need to tell the nozzleman applicants to fill out the company address, rather than their home address, on the information form for the exams.

In Summary

Whew, that's a lot of information, isn't it? The biggest recent change is the new shotcrete NIT certification that gives shotcrete contractors a good option for exposing their nozzleman trainees to the comprehensive shotcrete knowledge our full-day ASA Shotcrete Education class

More than one core drilling rig with crews who have experience in the operation

provides. It also allows the NITs to take the written and performance exams, and if successful on the exams, be upgraded to the full certification status upon reaching the required 500 hours. The other relatively new provision is clarifying the need for at least 100 hours work experience in the process AND orientation.

ASA constantly strives to improve the consistency, quality, and relevance of our shotcrete nozzleman sessions. We have several examiners-in-training to increase the size of our Examiner pool and allow us to be more responsive to our Host's requests for session dates. Our Education committee has a standing task to update and refine the education presentation. We work closely with ACI Certification to resolve issues that need clarification in the policy or procedures. We also closely review our process to streamline our administration and if needed suggest refinements to ACI Certification. If you have any questions about sessions, please contact Alice McComas at (248) 983-1702 or e-mail her at info@shotcrete.org. Also, if you have feedback for me on a past session, feel free to contact me directly at (248) 983-1701 or e-mail charles.hanskat@shotcrete.org.

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

Can Supplemental Consolidation Extend the Limits of Shotcrete Placement?

By Oscar Duckworth

In many major metropolitan regions of the United States, shotcrete methods are being used daily to place concrete within elements incorporating large, highly congested reinforcement layouts. In the past, many thought that only form-and-pour methods could be used for these dense layouts. The increased use of shotcrete for these applications is primarily driven by the cost and labor savings that inherently result from shotcrete's efficiencies. Because shotcrete's compaction and consolidation qualities are directly attributed to high velocity, lower velocity that can occur in tightly congested reinforcement configurations being shot today can prove insufficient to provide adequate compaction.

For years, experienced shotcrete crews have used a hybrid of high-velocity placement with supplemental consolidation methods. The supplemental mechanical vibration techniques help consolidate the concrete and allow full encasement of congested reinforcement elements. Success with the hybrid placement requires careful attention to detail and experience by the shotcrete crews.

Current shotcrete technical documents, ACI 506.2-13, "Specification for Shotcrete;" ACI 506R-16, "Guide to Shotcrete;" and ACI CP-60, "Craftsman Workbook for ACI Certification of Shotcrete Nozzleman," do not recognize the use of mechanical vibration during shotcrete placement.

Fig. 1: Mockup panels with congested reinforcement patterns may require alternative methods to attain adequate consolidation

Lack of published guidance can lead to confusion for engineers, specifiers, and on-site inspectors if a vibrator is operated in conjunction with shotcrete placement.

Is the shotcrete industry comfortable with this hybrid placement process? Can the untrained misuse of mechanical vibration spell trouble ahead?

> "*shotcrete — concrete placed by a high velocity pneumatic projection from a nozzle.*"
> from ACI Concrete Terminology – CT-18

By definition, the shotcrete process is entirely dependent on high velocity. The velocity and impact force provide the energy required to achieve compaction and consolidation. A skilled crew using proper nozzling techniques can achieve full encasement within fairly dense reinforcement configurations. However, some congested reinforcement patterns may interrupt the flow of material and reduce the velocity before impact. This may reduce the ability to fully encase the reinforcing steel.

Whether cast or shot, the use of larger bars and increased reinforcement congestion presents distinct challenges to attaining full consolidation of concrete during placement. If congestion prohibits the use of internal vibrators with form-and-pour placement, alternative consolidation methods or designs must be considered. This includes use of external mechanical vibration, redesign of the reinforcement, or use of a self-consolidating concrete mixture. With shotcrete placement, such options do not exist.

Currently in structures with congested reinforcement, preconstruction testing (mockups) are used to validate the concrete materials, delivery equipment, and if the shotcrete crew can satisfactorily encase the structural reinforcement (Fig. 1).

Professional nozzlemen who routinely shoot complex mockup panels can immediately identify the exact location of areas within the panel that will be difficult to achieve encasement. Highly experienced shotcrete crews place concrete in these difficult areas through a combination of high-quality shotcrete placement techniques and supplemental consolidation.

TO UNDERSTAND WHY SUPPLEMENTAL CONSOLIDATION MAY BE NECESSARY—THINK LIKE A NOZZLEMAN

For the shotcrete nozzleman, as reinforcement congestion increases, the complexity of placement increases. As complexity increases, so does the potential for consolidation quality to be compromised. It is important to understand that nozzlemen must function within certain natural limitations of the shotcrete process. Nozzlemen must use impact energy derived from velocity as the only means to consolidate the material.

As obstacles between the nozzle tip and the receiving surface increase, the nozzle stream is affected in two distinct ways. Initially, because the nozzle stream cannot be directed into all the shadow areas behind reinforcing bars due to its impeded path, some bars may not receive material at the proper velocity or angle. Larger bars, in conjunction with more restrictive reinforcement patterns, tend to decrease the likelihood that velocity alone can successfully encase and consolidate all the material adequately. Voids can occur within shadow areas behind bars that are within the shadow of other bars. Second, the mixture proportions tend to become segregated by the high-velocity nozzle stream's interference among congested reinforcing bar layouts. Higher quantities of loose, unconsolidated material, or rebounded materials—rather than well consolidated materials—can become embedded, especially within areas that cannot be effectively blown clear with the blow pipe.

Experienced nozzlemen who direct the nozzle stream skillfully, have proper placement equipment, and use well-chosen concrete mixtures can overcome much of shotcrete's natural limitations. But beyond these, nozzlemen have few additional tools to counteract these limitations. In most instances, the nozzleman is the ONLY person that can make a visual observation of whether acceptable consolidation is occurring during placement. Unfortunately, it is difficult to quantify the degree of congestion that may or may not be successfully encased due to the natural limitations to the process (Fig. 2).

WHAT IS SUPPLEMENTAL CONSOLIDATION?

In heavily congested reinforcing layouts, high-quality shotcrete placement techniques alone may not always assure adequate encasement. Thus, supplemental consolidation should be considered as a method of supplying additional consolidation energy for proper placement techniques. Mechanical consolidation using properly sized concrete vibrators have been incorporated with form-and-pour methods for more than 75 years. However, use with the shotcrete process is not widely known or documented.

Freshly placed shotcrete is highly susceptible to disruption from movements. Experienced placement crews incorporating mechanical vibration in conjunction with shotcrete placement techniques must carefully balance the mechanical energy required to consolidate the material, but not displace it. By comparison, form-and-pour methods use

Fig. 2(a) and (b): Mockup panels with congested to extremely congested reinforcement patterns mechanical vibration as the primary means of consolidation because rigid formwork withstands the material pressures during vibration. With shotcrete—because there are no restraining forms—mechanical vibration, if used improperly, can (and will) interfere with in-place quality. Vibration can unintentionally disturb freshly placed material to the point that delaminations, internal cracks, sags, and fallouts can occur. When vibrators are used with shotcrete, experience, timing, and properly selected equipment will be the determining factor in the success of supplemental consolidation.

UNDERSTANDING MECHANICAL VIBRATION

Concrete vibrators used for form-and-pour methods have not changed significantly for decades. Vibrators use a rotating counterweight encased within a steel body to produce powerful oscillations. As the vibrator is immersed in the concrete, a momentary fluidized puddle of highly agitated material occurs within a small area surrounding the vibrator known as the radius of action. Within the vibrator's radius of action, strong agitation changes the material adjacent to the vibrator to temporarily act in a more viscous, fluidized state, allowing the material to simultaneously release trapped air, consolidate tightly, and potentially segregate.

Manufacturers offer various lengths, exterior diameters, horsepower ratings, and oscillation frequencies to match their intended purpose. Because concrete is a mixture with many components of various weights, vibration can segregate the material as the oscillations cause heavier aggregates to fall and the lighter paste to rise. Heavier high-powered vibrators have a wide radius of action and work well for large elements and coarse mixtures but can quickly segregate material if used improperly. Small pencil vibrators, usually about 1 in. (25 mm) in diameter, are less likely to segregate materials, but have an effective radius of action of just a few inches and may lack the necessary energy to consolidate much more than the smallest element.

The vibrator's oscillation speed or frequency is important to the proper choice of a vibrator. Most common vibrators that plug into 120 or 240VAC household current can only rotate at about 3600 rotations per minute due to the limitations of the available alternating currents' 60-cycles-per-second rate. This low-frequency oscillation speed tends to consolidate concrete material well but unintentionally shakes the mixture's large aggregates downward excessively, causing segregation. As the frequency of the oscillations increase, large aggregates are less (or not at all) affected, so the material's movement is more uniform, diminishing the risk of segregation. This behavior is comparable to the behavior of dental, jewelry, or industrial ultrasonic cleaners, which vibrate a cleaning solvent at very high frequencies. High-frequency oscillations effectively dislodge stains or contaminants but will not shake even the smallest items. Because of the benefits of high-frequency oscillation, many "high-cycle" direct-current or battery-powered vibrators are available and are designed to function at 10,000 rpm or higher.

APPLYING MECHANICAL VIBRATION TECHNIQUES TO SHOTCRETE

With shotcrete, what is the best method to accomplish supplemental consolidation using a vibrator? Because vibration can unintentionally disturb rather than consolidate in-place material, the vibrator's size, frequency, and methodology become far more critical than with other concrete applications. Smaller pencil-style vibrators, which operate at very high frequencies, tend to work best.

Because freshly placed shotcrete can be easily damaged by vibration, the material must be as tightly placed as possible through proper nozzling techniques and the vibrator operated *only* as a means to assist, rather than act as the primary means of consolidation. Consolidation of poorly placed material or low-velocity placement methods using vibration as the primary means of consolidation should not be considered.

Supplemental consolidation requires that the material be carefully placed with vibration only used to help consolidate any remaining smaller voids or shadow areas behind obstacles. Skilled operators focus the vibrator's activity only within these areas, working carefully to avoid movement of the in-place material outside the vibrator's radius of action. If operated carelessly, vibrators will damage in-place work. Because material being vibrated is not retained within formwork, over-vibration **will** cause the fluidized material to flow downward and outward, which can create cracks or delaminations; reduce internal cohesion; or break the bond between the shotcrete, the reinforcement, or the underlying material.

USE TIMING AND VISUAL INDICATORS

The vibrator operator must follow the nozzle closely, move quickly, and continually monitor both the shotcrete's upper bench surface and the areas immediately below the vibrator's radius of action. The operator should be able to recognize the visual indicators indicative of proper shotcrete vibration techniques. The upper surface should become smoother without dropping excessively. The area below the vibrator should flow outward *slightly* without bulging. If vibration is causing excessive movement, or displacing material away from the immediate work area, the vibrator is too large, or the material is being over-vibrated. Work should be stopped, and the problem must be corrected before continuing.

The use of a vibrator as supplementary consolidation of shotcrete can be an extremely valuable tool to counteract the natural limitations of the shotcrete process in congested structural concrete—but only if experienced personnel and properly chosen vibration equipment is paired with high-quality nozzling practices.

Can supplemental consolidation redefine the limits of where shotcrete placement can successfully provide well-consolidated concrete with fully encased reinforcing steel? It already has. Perhaps a future definition for shotcrete is:

> *shotcrete—concrete or mortar projected at high velocity where a combination of impact and supplemental consolidation, when needed, achieve compaction.*

Supplemental consolidation checklist:

- When in doubt whether an element can be successfully shot, ask the nozzleman. Occasionally, the nozzleman is the ONLY person capable of making a visual observation of whether supplemental consolidation may be necessary;
- Gather knowledge on the proper use of a vibrator before purchasing or using a vibrator with shotcrete;
- Choose a vibrator that is best suited for use with the shotcrete process. Small pencil-type vibrators with a frequency range of 10,000 rpm or above work best;
- Use vibration for supplemental consolidation of properly placed shotcrete—not as the primary means of consolidation for low-velocity placement or poorly placed shotcrete;
- Vibrator operator: learn to recognize the timing and visual indicators of proper supplemental consolidation. Follow the nozzleman closely and avoid over-vibration; and
- Nozzleman: learn to identify the visual indicators of proper supplemental vibration techniques. If material sags or becomes visibly damaged from vibration, internal damage from cracks or delaminations are likely; cut it out and replace the entire damaged section rather than simply repairing its surface with a trowel.

ACI Certified Nozzleman ***Oscar Duckworth*** *is an ASA and American Concrete Institute (ACI) member with over 25,000 hours of nozzle time. He has worked as a nozzleman on over 2500 projects. Duckworth is currently an ACI Examiner for the wet- and dry-mix processes. He serves on the ASA Board of Directors and as Chair of ASA's Education Committee. He continues to work as a shotcrete consultant and certified nozzleman.*

Compatible Shotcrete Specifications and Repair Materials

By William Clements and Kevin Robertson

Concrete repair projects can often be completed using a variety of different repair materials and methods, though in some cases, the specific performance requirements of a project may dictate use of a specific material or method. Shotcrete is often used as a repair method to replace other methods such as form-and-pour to reduce labor costs and accelerate the construction schedule. Shotcrete is the best method when access to the repair area is limited in location and availability (Fig. 1). In selecting a repair method, a repair material must then be selected that is compatible with the concrete substrate, durable in the expected exposure conditions, and meets the structural requirements detailed by the design professional responsible for the repair. Ideally, these important criteria would be evaluated by the design professional and incorporated into the project specification to address the specific requirements of the project based on the expected service life of the repair. However, some design professionals, in developing their project specifications, are not well informed about the specific details for quality shotcrete placement and may miss or overlook important repair criteria.

Fig. 1: Remote dam repair using dry-mix shotcrete and a cofferdam[1]

The service life of any repair depends on the repair material's successful bond to the substrate, resistance to the exposure conditions, and crack resistance while in service. Even if the repair material exhibits excellent durability properties, if cracks develop either in the repair material or around the perimeter of the repair area, they allow easier ingress of corrosive agents such as water and chlorides to the embedded reinforcing steel. Thus, when considering these factors, the repair material must be as compatible as possible with the substrate to reduce the potential for cracking.[2]

SPECIFICATIONS

As with most specifications in the construction industry, concrete repair specifications typically use either a prescriptive specification or a performance specification. Prescriptive specifications either reference the actual repair product(s) by name or the constituents or characteristics of the repair material. In contrast, a performance specification outlines the performance requirements of the repair material after placement in accordance with applicable standards. In general, there is currently a trend towards performance specifications, but in North America, both ACI 318[3] and CSA A23.1/A23.2[4] still use a hybrid method of both prescription and performance when classifying concrete.[5] There are cases where contractors prefer to submit an "or equal" alternative to prescribed products based on past experience. The contractor may propose the shotcrete method in lieu of form-and-pour. It can be simpler for a contractor to submit shotcrete placement for a performance specification, as the contractor and manufacturer simply need to display compliance with the project specification through the appropriate submittals to obtain approval. This process does become much more difficult however, when the project specification presents a product or certain performance criteria that do not match the typical test methods applicable to shotcrete. ACI 506.2-13, "Specification for Shotcrete"[6] includes mandatory provisions for the commonly tested performance characteristics such as compressive strength and flexural strength, noting that any hardened test samples must be produced from sprayed test panels. Unfortunately,

Table 1: Test Methods for Repair Mortars Compared to the Corresponding Method for Shotcrete

Property	Repair mortar test method	Repair mortar specimen type	Shotcrete test method	Shotcrete specimen type
Compressive strength	ASTM C109/ C109M[8]	Cast cube (2 x 2 in.)	ASTM C1604/ C1604M[7]	Core (3 in. Ø)
Flexural strength	ASTM C348[9]	Cast beam (1.5 x 1.5 x 6.5 in.)	ASTM C78/C78M[10]	Sawed beam (6 x 6 x 21 in.)
Splitting tensile strength	ASTM C496/ C496M[11]	Cast cylinder (4 x 8 in.)	ASTM C496/C496M[11] (modified)	Core (3 in. Ø)
Slant shear bond strength	ASTM C882/ C882M[12]	Cast cylinder (3 x 6 in., -30-degree incline)	ASTM C1583/C1583M[13] (Pulloff bond strength)	Tensile bond of core (3 in. Ø)

Note: 1 in. = 25 mm

it is common to see specifications or even technical data sheets from manufacturers of shotcrete materials showing results for test methods applicable to repair mortars and not for shotcrete. For example, the compressive strength of shotcrete should always be evaluated in accordance with ASTM C1604/C1604M,[7] but it is typical for manufacturers to present data in accordance with ASTM C109/ C109M.[8] ASTM C109/C109M involves manually consolidating shotcrete mortar into cube molds, as opposed to being shot, and is not representative of the in-place shotcrete that is compacted by high-velocity impact. An example of commonly specified test methods in a shotcrete repair specification compared to the corresponding applicable test method for shotcrete is presented in Table 1.

A common misconception when it comes to current shotcrete specifications for repair projects is where "low-velocity mortar spray" or "low-pressure mortar spray" is somehow considered equal to high-velocity dry-mix or wet-mix shotcrete. As noted in Table 1, the adapted ASTM test methods for compressive strength, flexural strength, and other test methods differentiate shotcrete from mortar. Low-velocity spraying involves pumping at a lower pressure and air flow than conventional wet-mix shotcrete, resulting in a much lower velocity placement. The main difference between both methods is the velocity at which the material is shot into place. Shotcrete has been characterized to travel at speeds of 45 to 78 mph (72 to 125 km/h), which produces a high impact force and fully consolidates the concrete in-place. Conversely, low-velocity mortar spray was developed and is essentially a method to replace hand-troweling of a repair material.[14] Low-velocity mortar spraying simply lacks the velocity required to fully encapsulate reinforcing steel and even wire mesh in most cases. In some of North America's construction markets, the shotcrete method has been given a bad reputation because the specifications have been written around low-velocity mortar spraying that was considered to be "as equal" to shotcrete. Both methods have their place in the repair industry depending on the type of repairs to be completed. When designing repairs that use wire mesh or reinforcing steel, high-velocity shotcrete must be used to have the ability to properly encapsulate the embedded reinforcing steel and not create voids behind the steel.

The shotcrete process selected can impact the mixture design of the concrete materials being shot. Wet-mix shotcrete materials must be pumped through the delivery pipe and hose prior to spraying. Wet-mix shotcrete commonly contains an air-entraining admixture to either provide durability in freezing-and-thawing environments, or to improve the pumpability of the material using the "high initial air content concept".[15] Using a high initial air content ranging from 10 to 20%, the "high initial air content concept" has been proven to increase the slump and pumpability of shotcrete during pumping, and due to high velocity impact of the shotcrete produce an in-place air content of 3 to 5% in place after shooting. In the case of dry-mix shotcrete where water is added at the nozzle, it is impossible to ascertain the air content because the concrete materials are not mixed to form the cement paste until water is added at the nozzle. Therefore, any test results presented for the mechanical and durability properties of a shotcrete repair material, whether wet-mix or dry-mix, should be from as-shot samples.

ADAPTING TEST METHODS TO THE SHOTCRETE PROCESS

The International Concrete Repair Institute (ICRI) technical data sheet protocol established in ICRI Guideline No. 320.3R,[16] provides a thorough list of both mechanical and durability parameters that should be provided on the technical data sheet of any repair material. Although the guideline details which ASTM standard test method should be followed for mortars and which methods should be followed for concrete, some adaptations are required when applying the protocol to a shotcrete material. Considering most of the test methods described in ICRI Guideline No. 320.3R and noted in Table 1 reoccur in concrete repair specifications from the industry, KING enlisted Laval University to execute a testing program for the required parameters using a silica fume-enhanced dry-mix shotcrete (KING MS-D1). All of the samples tested were obtained from coring or sawing conventional test panels (Fig. 2), spraying shotcrete onto previously cast concrete sections, or by

Table 2: Adapted Test Methods for Shotcrete using ICRI Guideline No. 320.3R

Property	Test method	Sample type	Result (28 days)
Flexural strength	ASTM C78/C78M	Sawed beam (6 x 6 x 21 in.)	1088 psi (7.5 MPa)
Splitting tensile strength	ASTM C496/C496M	Core (3 in. Ø)	645 psi (4.45 MPa)
Direct tensile strength	CRD-C 164[17]	Core (3 in. Ø)	500 psi (3.45 MPa)
Modulus of elasticity	ASTM C469/C469M[18]	Core (3 in. Ø)	4.2 x 10^6 psi (29.0 GPa)
Pulloff bond strength	ASTM C1583/C1583M	Tensile bond of core (3 in. Ø)	420 psi (2.9 MPa)
Slant shear bond strength	ASTM C882/C882M	Core (3 in. Ø-30-degree incline)	3335 psi (23.0 MPa)
Length change	ASTM C157/C157M[19]	Sawed beam (3 x 3 x 11.25 in.)	50% RH: -0.0494% 100% RH: +0.0122%
Coefficient of thermal expansion	CRD-C 39[20]	Core (3 in. Ø)	6.5 x 10^{-6}/°F (11.7 x 10^{-6}/°C)
Freezing-and-thawing	ASTM C666/C666M[21]	Sawed beam (3 x 3 x 11.25 in.)	100% durability factor
Salt scaling	ASTM C672/C672M[22]	Sawed slab (72 $in.^2$ surface)	0.04 lb/ft^2 (0.2 kg/m^2)
Chloride ion penetrability	ASTM C1202[23]	Core (4 in. Ø)	500 Coulombs

Note: 1 in. = 25 mm; 1 MPa = 145 psi

spraying oversized test samples for durability testing and then sawing the edges around the perimeter of the samples to remove sections of rebound and overspray.

The Slant Shear Bond Strength test (ASTM C882/C882M) was originally developed to test the bond strength of epoxy between two cast mortar sections. The concrete repair industry has since adopted a modified version of the test, wherein the concrete repair material is placed onto the hardened mortar dummy (Fig. 3) and then the composite cylinder is tested in compression.

The resulting load on the cylinder is divided by the area of the ellipse, resulting in a shear bond strength along the 30-degree plane of the bonding surface. To modify the test method to the shotcrete process, a concrete section was cast using the appropriate angle (Fig. 4), and then shotcrete was sprayed onto the concrete section. Cores were taken perpendicular to top surface of the composite sample to model the shotcrete being cast onto the mortar dummy as per the standard (Fig. 5).

Following the completion of the test program, it is apparent that most test methods for concrete materials can be adapted to the shotcrete process, although in some cases execution is more complicated. Table 2 presents the results of the testing program. When compared to typical requirements for concrete, it can be seen that dry-mix shotcrete is an excellent concrete repair material. Notably, the bond strength exhibited by the ASTM C882/C882M test samples were very high, and two of the five cores tested at 28 days

Fig. 2: Conventional square shotcrete test panels used for obtaining cores

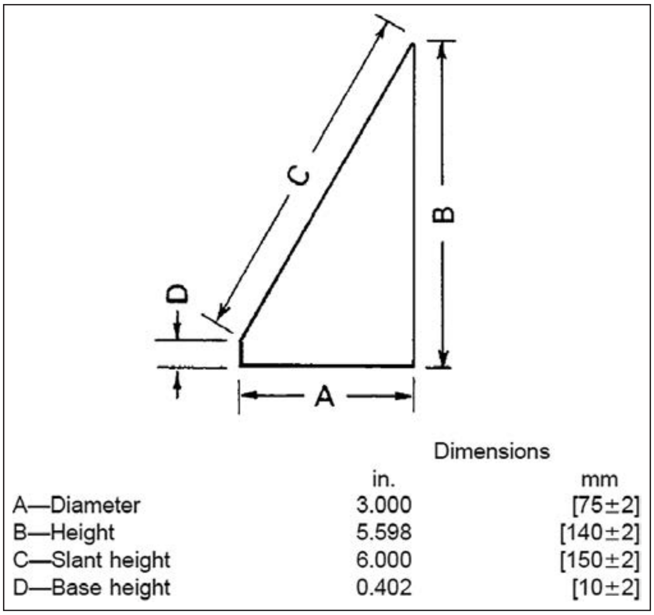


Fig. 3: Schematic of slant shear dummy section (ASTM C882/C882M)

failed with multiple vertical cracks as opposed to failing along the bond line.

DEVELOPING COMPATIBLE DRY-MIX SHOTCRETE

Almost all reinforced concrete structures will require some maintenance during their expected service life. The type and extent of repairs needed are a function of the structure's age, exposure conditions, original design, construction methods, and building materials used. Where possible, it is best to replace any concrete that is removed from the structure with a repair material that has physical properties similar to the substrate, such as compressive strength, modulus of elasticity, and coefficient of thermal expansion. This helps reduce potential debonding by ensuring that any physical movement, either due to loading or temperature changes in the substrate, are mirrored in the repair material. These properties do not, however, predict the inevitable volume change that a concrete repair material will undergo once in place. This volume change is a complex combination of chemical/autogenous shrinkage of the cement paste, drying shrinkage from moisture loss, and tensile creep (relaxation). Once the tensile forces of shrinkage exceed the tensile strength of the material, internal cracking can occur. If the tensile shrinkage forces exceed the bond strength of the repair material to the substrate, cracking can occur at the perimeter of the repair.

Even though shotcrete is very similar once shot to form-and-pour concrete, the shotcrete mixture design must be tailored to the process to facilitate pumping, optimize build-up while spraying, and to reduce rebound. The use of silica fume in shotcrete can greatly reduce rebound, increase build-up thickness, increase compressive strength, and reduce permeability.[24] Conversely, silica fume, with its high water demand, requires swift and proper wet curing techniques after shooting that if not followed will increase drying shrinkage and can increase the risk of cracking. To reduce the potential for shrinkage and improve compatibility, it may be beneficial to remove silica fume from the dry-mix shotcrete formulation, but the loss of productivity and efficiency due to increased rebound in the field would generally not be acceptable. Some potential techniques for reducing the shrinkage potential in shotcrete materials include the use of coarse aggregate, reducing the cementitious content, replacing portland cement with fly ash, and using polymer. To evaluate the effectiveness of these approaches to resist shrinkage potential requires a test method that captures all of the parameters noted previously as the shotcrete undergoes volume change.

Currently, the best test method for predicting the risk of cracking in a repair material is the AASHTO T 344[25] standard test method (ring test), which has recently been adapted to the shotcrete process at Laval University.[26] The method involves spraying shotcrete into a steel ring mold, which is mounted in an inclined overhead position to allow rebound to escape the mold (Fig. 6).

Following moist curing, the shotcrete ring is placed in a controlled environment at 50% (±5%) relative humidity and a temperature of 70 ± 2°F (21 ± 1°C). The stress developed

Fig. 4: Inclined precast mold for slant shear bond strength testing (ASTM C882/C882M)

Fig. 5: Composite core for slant shear bond strength testing (ASTM C882/C882M)

Fig. 6: Shotcrete being sprayed into inclined AASHTO T 344 rings

in the shotcrete ring is monitored using a data acquisition system, wherein cracking potential is then calculated as a function of the average stress developed and the age at which cracking occurs. Using a wet curing period of 3 days followed by drying, several mixture designs along with a proprietary mixture design developed by KING (HC-D1) were compared using the ring test to evaluate cracking potential.[27] The formula used and the age of cracking for each mixture design is presented in Table 3.

CONCLUSIONS

The shotcrete process can be used to achieve compatible concrete repairs offering a long service life. The combination of specifying the correct physical properties (test methods) and using the right shotcrete material helps achieve success in the field. The mechanical and durability properties of shotcrete should always be determined using samples that are shot and not cast, by adapting any applicable standards to the shotcrete process. The development of a highly

Table 3: Age of Cracking for Different Dry-Mix Shotcrete Formulas

Mix no.	Cement content (%)	Coarse aggregate (%)	Silica fume (%)	Fly ash (%)	Polymer (%)	Age of cracking AASHTO T 344 (days)
1	21	15	0	0	0	25
2	18.9	15	2.1	0	0	9
3	19.4	15	1.6	0	0	6.5
4	14.4	15	1.6	5	0	6
5	19.4	15	1.6	0	2.0	7
6 (HC-D1)	*	*	*	*	*	40

**Proprietary mixture design*
Note: The remainder of the formula consisted of sand

compatible dry-mix shotcrete with a very low cracking potential shows promise and testing of the other key properties as described in this article are currently underway.

References

1. Côté, R.; Ferland, H.; and Robertson, K., "McCormick Dam & Power Station: Submerged Concrete Repairs," *Shotcrete*, V. 17, No. 1, Winter 2015, pp. 36-39.

2. McDonald, J.E.; Vaysburd, A.M.; Emmons, P.H.; Poston, R.W.; and Kesner, K.E., "Selecting Durable Repair Materials: Performance Criteria–Summary," *Concrete International*, V. 24, No. 1, Jan. 2002, pp. 37-44.

3. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 519 pp.

4. CSA A23.1/A23.2, "Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete," CSA Group, Mississauga, ON, Canada, 693 pp.

5. Tanesi, J.; Da Silva, M.G.; Gomes, V.; and Camarini, G., "From prescription to performance: international trends on concrete specifications and the Brazilian perspective," *IBRACON Structural and Materials Journal*, V. 3, No. 4, Dec. 2010, pp. 420-431.

6. ACI Committee 506, "Specification for Shotcrete (ACI 506.2-13)," American Concrete Institute Farmington Hills, MI, 2014, 12 pp.

7. ASTM C1604/C1604M, "Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete," ASTM International, West Conshohocken, PA, 5 pp.

8. ASTM C109/C109M, "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)," ASTM International, West Conshohocken, PA, 10 pp.

9. ASTM C348, "Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars," ASTM International, West Conshohocken, PA, 6 pp.

10. ASTM C78/C78M, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading," ASTM International, West Conshohocken, PA, 5 pp.

11. ASTM C496/C496M, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," ASTM International, West Conshohocken, PA, 5 pp.

12. ASTM C882/C882M, "Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete By Slant Shear," ASTM International, West Conshohocken, PA, 4 pp.

13. ASTM C1583/C1583M, "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)," ASTM International, West Conshohocken, PA, 4 pp.

14. Hanskat, C., "Pneumatically Applied Concrete: A Confusion of Terminology," *Shotcrete*, V. 18, No. 4, Fall 2016, pp. 22-25.

15. Jolin, M., and Ginouse, N., "Recent Research in Wet-Mix Shotcrete at Laval University," 3 Congresso Brasileiro de Tuneis E Estruturas Subterraneas, 2012, São Paulo, Brazil, p. 19.

16. ICRI 320.3R,"Guideline for Inorganic Repair Material Data Sheet Protocol," International Concrete Repair Institute, Inc., St. Paul, MN, 9 pp.

17. CRD-C 164-92, "Standard Test Method for Direct Tensile Strength of Cylindrical Concrete or Mortar Specimens," US Army Corps of Engineers, Washington, DC, 4 pp.

18. ASTM C469/C469M, "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," ASTM International, West Conshohocken, PA, 5 pp.

19. ASTM C157/C157M, "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," ASTM International, West Conshohocken, PA, 8 pp.

20. CRD-C 39-81, "Test Method for Coefficient of Linear Thermal Expansion of Concrete," US Army Corps of Engineers, Washington, DC, 2 pp.

21. ASTM C666/C666M, "Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing," ASTM International, West Conshohocken, PA, 7 pp.

22. ASTM C672/C672M, "Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals," ASTM International, West Conshohocken, PA, 3 pp.

23. ASTM C1202, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration," ASTM International, West Conshohocken, PA, 8 pp.

24. Wolseifer, J., and Morgan, D.R., "Silica Fume in Shotcrete," *Concrete International*, V. 15, No. 4, Apr. 1993, pp. 34-39.

25. AASHTO T 344, "Standard Method of Test for Estimating the Cracking Tendency of Concrete," American Association of State and Highway Transportation Officials, Washington, DC, 6 pp.

26. Girard, S.; Jolin, M.; Bissonnette, B.; and Lemay, J-D, "Measuring the Cracking Potential of Shotcrete," *Concrete International*, V. 39, No. 8, Aug. 2018, pp. 44-48.

27. Menu, B.; Pépin Beaudet, A.; Jolin, M.; Bissonnette, B.; and Molez, L., "Évaluation quantitative de la sensibilite a la fissuration du beton projeté au moyen de l'essai de retrait restreint annulaire," 19[e] Edition des Journées scientifiques du Regroupement Francophone pour la Recherche et la Formation sur le Béton (RF)[2]B, July 2018, Anglet, France, 10 pp.

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Performance and Prescription Based Specification

By D.R. "Rusty" Morgan, Ph.D

In prescription-based specifications the engineer will typically set out in detail all requirements for the materials and shotcrete mixture proportioning as well as the type of equipment required for batching, mixing, supply, and application of shotcrete. In performance-based specifications the engineer will specify the required performance characteristics for the shotcrete and let the contractor select the materials, mixture proportions, type of equipment and application procedures to be used. In general, performance-based specifications are preferred to prescription-based specifications in that they encourage innovation and introduction of new technology and generally result in lowest cost to the owner. Let us examine in some detail the differences between these two different methods of specifying shotcrete.

PRESCRIPTION-BASED SPECIFICATIONS

In *prescription-based* specifications the engineer will typically specify (in kg/m³ or lb/cu yd, or mass to volume ratios):

- The type and quantity of cement to be used (sometimes even specifying a particular brand name of cement).
- The type and quantity of supplementary cementing materials, such as fly ash, silica fume, blast furnace slag, or metakaolin, etc. to be used.
- The source of supply, gradation and quantity of coarse and fine aggregates to be used.
- The type (often including name brand) and dosage of all chemical admixtures to be used, e.g. water reducers, retarders, accelerators, superplasticizers, and air entraining admixtures for wet-mix shotcrete, or accelerators and dust suppressants for dry-mix shotcretes.
- The type (often including name brand), length, aspect ratio (length to equivalent diameter), and addition rate of steel or synthetic fibers to be added to the shotcrete, if required.

Alternatively, the engineer may specify that the contractor use a particular proprietary dry-bagged shotcrete mixture. Conceptually, both these prescription-based methods are acceptable, provided the contractor demonstrates proper mixing, batching, supply, application, and curing methodology and the engineer/owner is prepared to accept the resulting performance (in terms of compressive strength and other physical properties achieved) with these prescription mixes. What is unfair, however, is if the engineer requires the contractor to use a given prescription-based mixture formulation, and also meet certain performance specifications, e.g. meet compressive strength, flexural strength, toughness, shrinkage, etc. values. Unfortunately, from time to time, one still finds such specifications in bid documents. The contractor should be alerted to this and raise the issue with the specifying engineer prior to bid submittal in order to avoid being placed in a compromised position, should a prescription-based mix design fail to meet imposed performance requirements.

Table 1: Shotcrete Performance Specification Stave Falls, BC Hydroelectric Project

Property	Age, Days	Specified Limits
Maximum Water/Cement Ratio		0.45
Air Content-As Shot, % CSA A23.2-4C		4 + 1%
Slump, mm, CSA A23.2-5C		80 + 30
Minimum Compressive Strength, MPa CSA A23.2-14C	7 28	30 40
Maximum Boiled Absorption % Max. Volume of Permeable Voids % ASTM C642	7 7	8 17
Minimum Flexural Strength, MPa Min. Flexural Toughness ASTM C1018 & Ref 1	7 7	4.0 Toughness Performance Level III
Shotcrete Core Grade ACI 506.2-95		Mean <2.5 Individual <3

PERFORMANCE-BASED SPECIFICATIONS

In *performance-based* specifications the engineer will often specify the following items:

- The type of cement e.g. ASTM C150 type 1.
- The type and sometimes minimum and maximum permissible addition rate of supplementary cementing material (e.g. fly ash or silica fume) as a percent by mass of cement. Note: Supplementary cementing materials are often used for reasons such as mitigation of the potential for alkali aggregate reactivity, sulfate attack, heat of hydration, chloride intrusion, etc. As such, the engineer is fully entitled to specify their use in a performance-based specification.
- The maximum size aggregate permitted and an aggregate gradation envelope that the combined coarse and fine aggregates should satisfy e.g. ACI 506R-90, Table 2.1, Gradation No. 2.
- The types of chemical admixtures that should be used.
- Whether the use of shotcrete accelerators is permitted.
- Whether steel or synthetic fibers should be used. Note: Sometimes engineers will specify a minimum tensile strength for steel fibers (e.g. minimum 1000 MPa) in order to guard against use of lesser quality fibers. Specifying fiber length and aspect ratio as well is, however, considered inappropriate in a performance-based specification.
- The allowable slump range at discharge into the pump for wet-mix shotcretes.
- The in-place (as-shot) air content in wet-mix shotcretes. Note that about half the as-batched air content is lost during shooting and in order to end up with 4 ± 1% air content in-place, it is usually necessary to start with about 8 to 10% air content in the shotcrete discharged into the pump. The as-shot air content can be determined by shooting directly into an ASTM C231 air pressure meter base and then conducting the test in the normal way used for plastic concrete.
- For accelerated mixes the engineer may specify maximum initial and final setting times. Such tests should be conducted on shot test panels using the ASTM C1117 Penetration Resistance test method.
- The compressive strength, typically at 7 and/or 28 days. For accelerated shotcretes, earlier age strengths may also be specified, e.g. 8 hour, 12 hr, or 24 hr. strengths, if this is an important requirement for the construction process.
- For fiber-reinforced shotcretes, flexural strength at 7 and/or 28 days is often specified, together with flexural toughness.

Table 2: Shotcrete Mixture Design
Stave Falls, BC Hydroelectric Project

Material	Mass(kg)	Bulk Density (kg/m3)	Volume (m3)
Portland Cement, CSA Type 10	385	3150	0.122
Silica Fume	50	2100	0.0238
Steel Fibres	59	7860	0.0075
Coarse Aggregate, 14-5 mm	520	2759	0.1885
Fine Aggregate, SSD	1200	2662	0.4508
Water	180	1000	0.1800
Water-Reducing Admixture	1.76L	1000	0.0018
Superplasticizer	3.5 L	1000	0.0035
Air Content as shot	4.0%		0.0408
Total	2399		1.0188

Slump (after superplasticizer addition) = 70 ± 20 mm
Water: (Cement + Silica Fume) Ratio = 0.41
Calculated Plastic Density = 2355 kg/m3
Accelerator added at nozzle as required

Table 3: Shotcrete Compressive Strength, Boiled Absorption and Volume of Permeable Voids Performance Test Results, Stave Falls, BC Hydroelectric Project

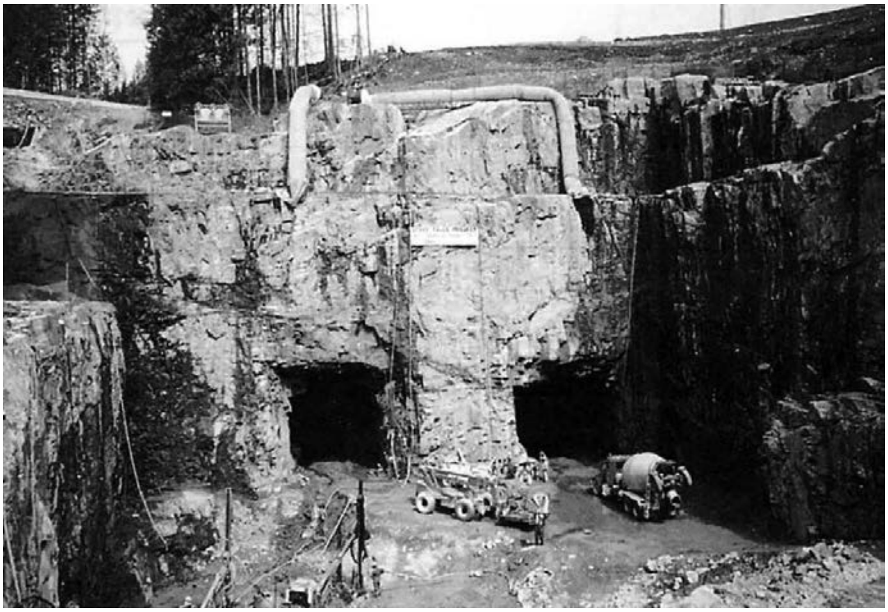
Panel No.	Compressive Strength (MPa) At 7 days	Compressive Strength (MPa) At 28 days	Boiled Absorption (%)	Volume of Permeable Voids (%)
1	47.5	71.5	4.6	10.5
2	45.1	68.6	3.4	8.1
3	38.5	66.7	4.9	11.0
4	48.0	72.2	3.5	8.1
5	36.8	56.6	4.8	11.0
6	36.7	47.0	6.2	13.7
7	38.5	57.7	5.9	13.3
8	33.0	45.9	5.8	13.2
9	36.8	62.0	4.5	10.2
Mean	40.1	60.9	4.8	11.0
Standard Deviation	5.4	9.9	1.0	2.1
Spec.	Min. 30	Min. 40	Max. 8	Max. 17

Table 4: Shotcrete Flexural Strength and Toughness Performance Test Results
Stave Falls, BC Hydroelectric Project

Panel No.	First Crack Flexural Strength MPa	Ultimate Flexural Strength MPa	ASTM C1018 Toughness Parameters					Japanese Toughness Factor (kNmm)	Japanese Toughness Factor (MPa)	Toughness Performance Level
			I_{10}	I_{30}	I_{60}	$R_{10,30}$	$R_{30,60}$			
1	3.77	4.31	10.5	31.1	57.2	103	87.1	21.70	3.13	III-IV
2	5.17	5.26	9.3	26.6	45.5	86.5	62.8	23.26	3.28	IV
3	4.66	4.77	8.8	25.6	46.2	84.1	68.8	21.92	3.17	IV
4	5.86	5.92	7.6	23.7	40.1	80.3	54.6	23.55	3.34	IV
5	4.49	4.52	9.6	27.6	49.1	89.7	72.0	23.21	3.24	IV
6	4.67	4.67	8.1	22.8	41.6	73.7	62.4	17.60	2.96	IV
7	4.83	4.83	8	22.8	41.8	74.2	63.4	22.77	3.10	III-IV
8	4.13	4.25	9.3	28.3	53.9	94.7	85.7	25.26	3.50	IV
9	4.37	4.37	8.0	22.1	40.7	70.8	62.0	17.99	2.79	III-IV
Mean	4.66	4.77	8.8	25.6	46.2	84.1	68.8	21.92	3.17	IV
Standard Deviation	0.60	0.53	1.0	3.0	6.1	10.6	11.1	2.55	0.21	
Spec.	Min. 4	Min. 4								Min. III

In North America flexural toughness is usually determined using the ASTM C1018 test method. There are, however, various ways of interpreting the data from this test method, e.g. toughness indices, residual flexural strengths calculated from toughness indices (or directly from the load vs deflection curve), Japanese JSCE-SF4 toughness parameters, toughness performance levels, etc. For more details on this subject see Reference 1.

- Some engineers specify limits on values for boiled absorption and volume of permeable voids in tests conducted to ASTM C642 on cores extracted from shotcrete test panels. Correspondence has been found between durability and resistance to leaching in shotcrete linings and these parameters.
- Some engineers also place limits on the maximum allowable water/cement ratio; control of this parameter helps to prevent excessive water addition to the shotcrete, which could adversely affect shrinkage, cracking, and durability of the in-place shotcrete.
- Finally, for reinforced shotcrete linings the (somewhat controversial) ACI 506.2-95 Core Grade system is sometimes specified. This test is usually used to prequalify nozzleman for shooting on the project, but is also sometimes used to evaluate the adequacy of encasement of reinforcing steel on the job. It should, however, be used with caution, as interpretation of core grading is somewhat subjective.



BC Hydro Stave Falls Hydroelectric Project: Downstream outlet of SFRS-lined pressure head race tunnel.

CASE HISTORY EXAMPLE OF A PERFORMANCE SPECIFICATION

A performance specification for a wet-mix, air-entrained, steel fiber-reinforced shotcrete for use in the Stave Falls Hydroelectric tunnel lining project in British Columbia, Canada (Reference 2) is shown in Table 1. This specification was for a high quality hydro power pressure headrace tunnel final lining with a 70-year design life. Table 2 shows the mixture design used by the contractor. The contractor was able to consistently meet the specified performance requirements for the project. Table 3 shows actual compressive strength and boiled absorption and volume of permeable voids test results for the first 9 of over 40 test panels shot on the project. (One test panel was shot for each day of shotcrete production or every 50 m^3 (65 cu.yd.) of shotcrete, whichever occurred first). Table 4 shows flexural strength and toughness test results for these same test panels.

CLOSURE

The specifying engineer should avoid placing unnecessary limits on the contractor regarding shotcrete batching, mixing, supply, and application procedures. While it is perfectly legitimate to specify whether the wet-mix or dry-mix shotcrete process should be used on a project, it may be unnecessarily restrictive to write prescription-based specifications which allow the contractor to only use central mix batching, with transit mixer supply, and manipulator arm placement of the shotcrete. The contractor may, for a given site, be able to produce an economical, high-quality shotcrete, meeting all the engineers/owners expectations using a site-produced, dry-batched, pre-mix supply and hand nozzling from a platform mounted on a manlift (as is currently being successfully used in several projects in North and South America).

In summary, the engineer is encouraged to write performance-based specifications. The engineer should tell the contractor what performance is required and let the contractor select the materials, mixture proportions, and production methods. This will usually result in the lowest cost shotcrete installation for the owner. The owners interests can be protected by the engineer specifying and enforcing a suitable quality assurance (QA)/quality control (QC) testing program. Good guidance regarding preparation of shotcrete specifications and design of suitable QA/QC programs is provided in ACI 506.2-95, ACI 506R-90 and References 3 and 4.

References

1. Morgan, D.R., Chen, L. and Beaupre D., Toughness of Fibre Reinforced Shotcrete, Shotcrete for Underground Support VII, Telfs, Austria, June 1995, published by ASCE, pp. 66-87.
2. Ripley, B.D., Rapp, P.A. and Morgan, D.R., Shotcrete Design, Construction and Quality Assurance for the Stave Falls Tunnel, Tunnelling Association of Canada, Canadian Tunnelling, 1998, pp. 141-156.
3. AASHTO-AGC-ARTBA Joint Committee, Task Force 37 Report, Guide Specifications for Shotcrete Repair of Highway Bridges, February 1998, published by AASHTO, Washington, DC pp. 108.
4. Morgan, D.R. and Heere, R., Quality Management of Shotcrete in North America, Laich SA Colloquium on Shotcrete Technology, Wildegg, Switzerland, September 26, 1997, p. 8.

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Misconceptions about Shotcrete—True Stories from ASA Technical Inquiries

By Charles Hanskat

As Executive Director and Technical Director for ASA, I get the unique opportunity to tackle a number of technical inquiries every month about shotcrete. Over the last couple of years, we've seen a sharp increase in inquiries from engineers, architects, and owners about pool and water feature installations. Likely part of this increase is the publication on our website of pool position statements **(www.shotcrete.org/products-services-information/resources/).**

A few of these inquiries were simply questions about best practices, but many have resulted from issues during or after construction. These are true stories. Believe me, I couldn't make some of these up.

Inquiry: A pool owner called and asked, "My shotcrete contractor had some delays while shooting our pool. The concrete got too hard to pump through the machine, so they took the concrete out of the truck in wheelbarrows, and then hand packed the concrete into the remaining open spots in the floor, steps, and benches. The contractor said they do this all the time. Is this OK?"

Misconception: Concrete intended to be shotcreted doesn't need to be physically shot.

Fact: Shotcrete by its definition is concrete pneumatically placed at high velocity. These velocities average from 50 to 80 mph (80 to 125 kmh). The energy released by impact of this high-velocity material provides compaction and consolidation of the concrete. Without the velocity and impact of shooting the concrete, alternative methods of consolidation must be used to eliminate voids and densify the concrete. Hand packing of very stiff, unpumpable material does not provide the compaction effort needed, so likely the concrete in-place has random voids and poor bond to adjacent concrete. Overall, these hand-packed sections will have less strength, reduced durability, and because this is a pool—greater permeability.

Inquiry: A pool owner in Arizona called after cracks formed in their new pool shell. The contractor had told them they needed to "water" the pool twice a day to prevent cracks, which they did, but cracks still formed.

Misconception: Adequate curing of shotcreted concrete surfaces is just dampening the surface occasionally.

Fact: Proper curing means keeping the concrete surface continuously damp. Curing for 7 days is recommended for shotcrete. Wet curing with water is preferred to using spray-on curing membranes. ACI 308R-01, "Guide to Curing Concrete," states "The objectives of curing are to prevent the loss of moisture from concrete and, when needed, supply additional moisture and maintain a favorable concrete temperature for a sufficient period of time." Curing is essential to allow the cement in the concrete to continue to hydrate. Hydration of the cement is how concrete builds strength, reduces permeability, and improves durability. Because shotcrete has a relatively low water-cementitious materials ratio (*w/cm*) compared to most placed concrete in floors with *w/cm* of 0.50 or greater, it would benefit greatly from supplying additional curing water. ACI 308.1-11, "Specification for Curing Concrete," requires for wet curing: "Keep the concrete surfaces continuously wet. Do not allow alternate wetting and drying of concrete surfaces." One would expect that the hot, dry, and potentially windy conditions prevalent in Arizona would create high evaporation rates and wetting the pool surface once or twice a day would not provide a continuous supply of supplemental water.

Inquiry: Another pool owner called about cracking in the coves, benches, and steps in their new pool. Investigating further, they found substantial delaminations and voids below the surface in many of these areas. I asked, "Did you watch the shotcreting procedure?" They answered "Yes." I then asked, "Did you ever see any concrete or material shoveled out of the pool?" Answer: "…No."

Misconception: Some shotcrete contractors feel shotcrete rebound and overspray is able to be left in the floor and coves, or shoveled up into the benches because it will be covered up by a layer of "good" shotcrete and won't affect the structural integrity or watertightness of the pool shell.

Fact: When shotcrete impacts a surface, the material that bounces off is called "rebound." This rebound material is mostly aggregate (sand and rock) and much less paste than in the shotcrete mixture design. Thus, rebound material is substantially weaker and more porous than the shotcrete mixture supplied. When rebound is incorporated in any final shotcreted section, one is introducing a layer of weakness within the concrete section. The section will then not act monolithically, as the designer intended; plus, it gives a weak plane in the shell that will encourage cracking and delaminations when the pool is exposed to wetting/drying and seasonal temperature variations. Rebound and overspray must always be removed and not incorporated in any of the structural pool shell.

Inquiry: An engineer working on a large free-form concrete fountain basin called and asked, "Our shotcrete contractor said we needed to use wet-mix shotcrete because dry-mix is porous and needs extra coatings or plastering to make the fountain basin watertight. Is this true?"

Misconception: Dry-mix is more porous than wet-mix, and not acceptable for liquid-containing pools or structures because it would require additional coating to provide the desired serviceability.

Fact: Dry-mix shotcrete produced with quality materials, good mixture design, proper equipment, and experienced nozzlemen will produce concrete in-place equal to concrete produced using a wet-mix process. Dry-mix will actually tend to have a lower *w/cm*. The perception that dry-mix is more porous may occur because dry-mix water content is controlled by the nozzleman. An inattentive nozzleman or inadequate water pressure may allow dry spots in the work. These areas are definitely more porous, but should not be present in quality shotcrete.

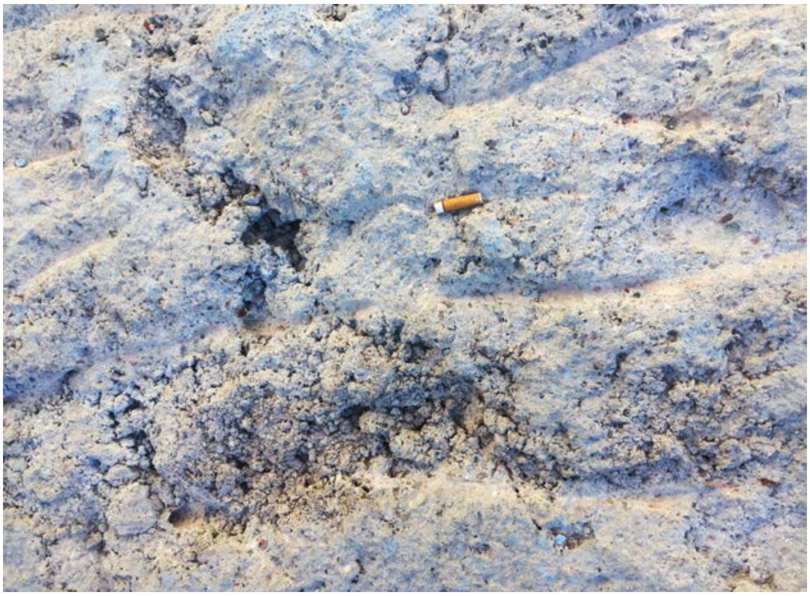

Fig. 1

Fig. 2

Inquiry: Here's an interesting inquiry: "The plaster color installed in my pool was the wrong color. The plaster has been chipped out. My concern is damage to the shotcrete shell in the process. There are deep holes, gouges, and there was water seepage in a few areas behind the shotcrete. There is also evidence of honeycombed areas in the shotcrete as well as some other shotcrete concerns since reading up on the shotcrete process. I'm being told that they will just plaster over these concerns. However, the plasterer says that plaster thickness should not exceed 7/8 in. (178 mm) thickness, but can be a little thicker around plumbing fixtures (refer to Fig. 1 and 2).

Misconception: Shotcrete can be shot rough and without close attention to full compaction because the surface will be covered with plaster and provide the final surface finish.

Fact: ASA has published a position statement, "Watertight Shotcrete for Swimming Pools." The position statement stresses that shotcrete can and should be built as an essentially watertight structural shell. Further, shotcrete can be finished to very uniform surface tolerances and finishes. A relatively thin, consistent layer of plaster is desired. Properly shotcreted sections should not have any significant voids or sandy, porous, or low-strength sections. From the images, it appears the contractor did not properly place the shotcrete for the pool. Plaster should not be used to fill substantial voids because it has significantly different mechanical properties (strength, thermal expansion/contraction, and shrinkage), and will not provide significant supplemental strength if the shotcreted shell has low strength or porous areas.

Inquiry: "Our pool sat over the winter, and we noticed many areas where the concrete looked sandy or porous. We had cores taken and tested and strengths resulted in 2500 psi (17 MPa). The contract indicated the shotcrete should be 4000 psi (28 MPa). We asked the contractor about the discrepancy, and he said that's normal. Concrete loses strength over time. Is that correct?

Misconception: Concrete loses strength over time.

Fact: Concrete usually has a significant amount of unhydrated cement that will hydrate over time. Continuing exposure to moisture and ongoing hydration increases strength, reduces permeability, and thus improves long-term durability. Concrete over 100 years old will still be strengthening. The contractor was wrong in stating concrete loses strength. Also, 2500 psi (17 MPa) is a very low compressive strength and indicates the use of improper materials, equipment, or poor nozzling techniques. ASA maintains that all shotcrete should have a minimum compressive strength of 4000 psi (28 MPa) at 28 days.

Inquiry: I am a structural engineer and we have recently begun work with a shoring contractor. We have been designing soil nails, micropiles, soldier piles, and so on with temporary and permanent shotcrete facings. The contractor has requested that some of our future designs use chain link mesh in lieu of welded wire mesh, particularly in temporary situations with walls under 10 ft (3 m). I understand that chain link is a cost-effective alternative and, according to the contractor, handles the shotcrete great. Is it acceptable reinforcing for shotcrete?

Misconception: Chain link fencing material is adequate for reinforcing shotcrete in underground applications.

Fact: Some mines have used chain link mesh in shotcrete in severely deforming ground and claim that it is better in holding the ground than mesh after large deformations, in which the shotcrete sustains major cracking with deformations. Other than for such unusual applications, we do not recommend the use of chain link mesh in shotcrete. It cannot be fixed "tight" and as such is susceptible to vibration and movement during shooting, resulting in shotcrete sloughing and formation of voids in the shotcrete. Also, the mesh interconnections are conducive to the formation of voids during shooting. Additionally, there doesn't appear to be any consistent material standards on the strength, flexibility, or brittleness of the steel (or other materials) used in the fencing material, so a designer has no way to establish the tensile or flexural strength of the concrete sections. In brief, don't use chain link mesh if you want to produce quality, durable shotcrete.

Inquiry: I've heard that dry-mix shotcrete is not acceptable for exposure to freezing-and-thawing conditions because it isn't air entrained. Is this true?

Misconception: Dry-mix doesn't have good freezing-and-thawing durability.

Fact: Dry-mix has decades of good performance in freezing-and-thawing environments, and should not be precluded from use in those exposures. Air entraining is just one aspect contributing to freezing-and-thawing resistance. Good air void spacing in the hardened concrete is the key to good performance of entrained air in concrete. Strength and to some extent permeability also affects performance. Because shotcrete generally has a lower *w/cm* than conventional form-and-place work, we experience faster strength gain and achieve higher strength over time. Shotcrete also often uses silica fume, fly ash, and other supplementary cementitious materials (SCMs) that increase strength and reduce permeability. Finally, air entraining admixtures are available for use in dry-mix.

Inquiry: I have heard for the best performance of shotcrete, you should avoid finishing and leave as a gun finish. Is this true?

Misconception: Shotcrete should not be finished because it reduces strength, serviceability, or durability of the concrete.

Fact: Shotcrete can be finished in a wide variety of ways, and has little if any detrimental effect on the strength and durability. However, proper finishing techniques should be used. Cutting and finishing (floating or brooming) by experienced finishers will help to produce sections with a consistent surface and section thickness. However, overfinishing or wetting the surface of hardening concrete (in shotcrete or cast concrete) can introduce microcracks in the surface layer. Also, requiring a smooth steel trowel finish will by its inherent nature bring extra paste and water to the surface, increasing the effective *w/cm* and thus reducing strength of that surface layer. However, this is the result for any cast concrete, and not limited to only shotcrete.

Inquiry: I have been told that I shouldn't use shotcrete because it will have more shrinkage cracks than my cast concrete walls.

Misconception: Shotcrete will have greater shrinkage cracking than form-and-place walls.

Fact: Early-age plastic shrinkage and long-term drying shrinkage are aspects of all concrete work. Plastic shrinkage cracking results from early, quick evaporation of water from the surface of the plastic, hardening concrete. With shotcrete placement, we will have our finished surface exposed to the air. Low humidity and hot or windy conditions will substantially increase the rate of evaporation. Good shotcrete contractors will evaluate appropriate methods to keep the surface damp and minimize or eliminate plastic shrinkage cracks. Long-term drying shrinkage is related to the paste content, amount and size of aggregate, and the *w/cm*. Shrinkage cracking is also related to the ability of the concrete to carry tension. The designer of the concrete structure also has a responsibility to design adequate movement joints to accommodate concrete shrinkage. Shotcrete tends to have a relatively high paste content so may have a slightly higher shrinkage potential. Conversely, shotcrete has a lower *w/cm* (0.30 to 0.42) as compared to most form-and-place (0.40 to 0.50), so would tend to have a lower shrinkage potential. Also, shotcrete tends to have earlier strength gain, and higher 28-day strengths (both compressive and tensile) than most form-and-place concrete. This reduces the shrinkage potentially causing cracks. Thus, considering the plusses and minuses, shotcrete may balance the shrinkage potential of form-and-place. More importantly, proper attention by the shotcrete contractor to the installation, through early, wet curing and keeping curing in place for at least 7 days will significantly help reduce the potential for cracking. Also, shotcrete mixtures can use shrinkage-reducing admixtures that will help limit drying shrinkage through the critical first year after placement.

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Shotcrete Placed in Multiple Layers does NOT Create Cold Joints

By Charles Hanskat

Designers and inspectors often confuse placement of multiple layers of shotcrete in building out a section with cold joints experienced in cast-in-place concrete construction. The American Concrete Institute's (ACI's) Concrete Terminology defines cold joint as:

> *"Cold joint—a joint or discontinuity resulting from a delay in placement of sufficient duration to preclude intermingling and bonding of the material, or where mortar or plaster rejoin or meet."*

In cast-in-place concrete construction, internal vibration is the most common method for providing adequate consolidation of the placed concrete. In cast-in-place work, a cold joint is formed when an initial lift of concrete becomes too stiff for penetration by the vibrator used to consolidate a subsequent lift. This thus precludes the "intermingling" of material in the definition. However, ACI 309R-05, "Guide for Consolidation of Concrete," indicates that if bond is obtained between cast sections, a cold joint is avoided. ACI 309R-05, Section 7.2, states:

> *"When the placement consists of several layers, concrete delivery should be scheduled so that each layer is placed while the preceding one is still plastic to avoid cold joints. If the underlying layer has stiffened just beyond the point where it can be penetrated by the vibrator, bond can still be obtained by thoroughly and systematically vibrating the new concrete into contact with the previously placed concrete; however, an unavoidable layer line will show on the surface when the form is removed."*

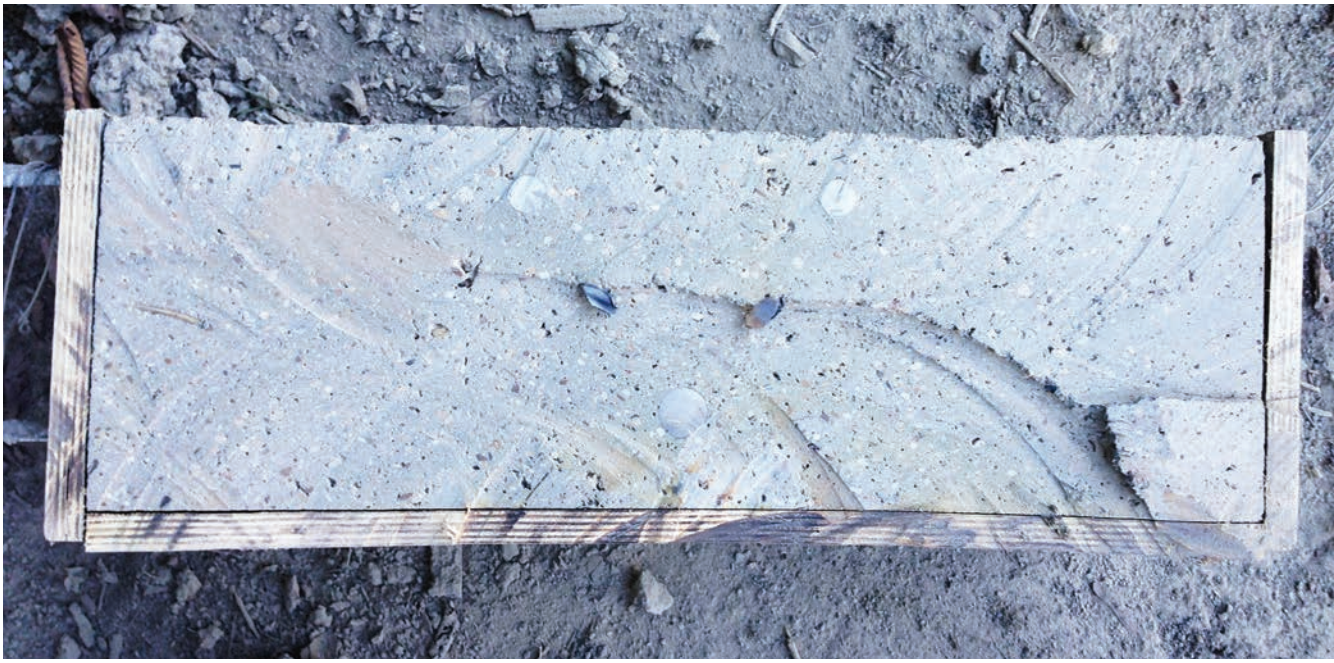
Shotcrete does not use internal vibration for consolidation of concrete. Instead, shotcrete provides thorough consolidation and densification by high-velocity impact of fresh concrete material on the receiving surface. It is well proven in laboratory testing that properly placed shotcrete is very well consolidated, and provides excellent strength and durability. The high-velocity impact of shotcrete on a hardened, previously shot layer (or existing concrete surface) provides a strong, abrasive blast to open up the surface, and then provides an immediate exposure of that hardened surface to fresh cement paste. As a result, shotcrete exhibits excellent bond to concrete and previously shot surfaces.

A study on shotcrete bond to concrete repair surfaces that included work on multi-layer shotcrete bond was conducted at Laval University (Beaupré 1999). The study looked at bond with multiple layers of shotcrete shot 4 hours, 1 day, and 28 days apart with four levels of surface finishing (no surface finishing, scratched with steel trowel, scratched and finished with wood trowel, rough broom finish). Table 1 shows the results from Beaupre's (1999) report. The report concluded that "it can be seen that, for the waiting period and the types of finish studied, there is no significant influence of these parameters on bond strength" and "With respect to the multi-layer bond strength of shotcrete, the presence of shotcrete/shotcrete interfaces does not seem to create a large reduction in shotcrete quality in terms of mechanical bond if no curing compound is used."

Table 1: Multi-layer bond strength in MPa (psi) (Beaupré 1999)

	Type of finish between layers (results with no curing compound)			
Time	*None*	*Scratch*	*Scratch + wood*	*Roughen with broom*
4 hours	2.1 (300)	1.8 (260)	2.1 (300)	1.9 (275)
1 day	NA	2.1 (300)	2.1 (300)	NA
28 days	NA	1.8 (260)	NA	2.0 (290)

Note: NA is not available



Sawed side of shotcrete test panel shot with multiple layers

Specified shotcrete bond strength for shotcrete to properly prepared concrete substrates generally ranges from 100 to 150 psi (0.69 to 1.00 MPa). If a curing compound is used on a layer, it should be completely removed before shooting subsequent layers of shotcrete.

In shotcrete construction, surface preparation between layers to provide full bond is important. ACI 506.2-13, "Specification for Shotcrete," specifically addresses this in the requirements of Sections 3.4.2.1 and 3.4.2.2 that:

> *"3.4.2.1 When applying more than one layer of shotcrete, use a cutting rod, brush with a stiff bristle, or other suitable equipment to remove all loose material, overspray, laitance, or other material that may compromise the bond of the subsequent layer of shotcrete. Conduct removal immediately after shotcrete reaches initial set.*
>
> *"3.4.2.2 Allow shotcrete to stiffen sufficiently before applying subsequent layers. If shotcrete has hardened, clean the surface of all loose material, laitance, overspray, or other material that may compromise the bond of subsequent layers. Bring the surface to a saturated surface-dry (SSD) condition at the time of application of the next layer of shotcrete."*

The shotcrete specification is actually more stringent than ACI 318-11, Section 6.4, on construction joints, because it requires removal of all potential bond-breaking materials immediately after initial set, as well as the cleaning and SSD conditions provided for in 3.4.2.2.

Thus, shotcrete placed in layers does not produce a "cold joint" as defined by ACI, because it produces excellent bond between the layers. This has been confirmed by visual inspection of numerous cores taken through multiple layers of shotcrete, where it is often impossible to identify where one layer stops and the other starts, unlike cold joints in cast-in-place work where the difference between lifts is readily apparent.

References

ACI Committee 309, 2005, "Guide for Consolidation of Concrete (ACI 309R-05)," American Concrete Institute, Farmington Hills, MI, 36 pp.

ACI Committee 506, 2013, "Specification for Shotcrete (ACI 506.2-13)," American Concrete Institute, Farmington Hills, MI, 40 pp.

ACI Committee 318, 2011, "Building Code Requirements for Structural Concrete and Commentary (ACI 318-11)," American Concrete Institute, Farmington Hills, MI, 503 pp.

Beaupré, D., 1999, "Bond Strength of Shotcrete Repair," *Shotcrete*, V. 1, No. 2, Spring, pp. 12-15.

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Slump - The Most Misunderstood Characteristic of Wet-Mix Shotcrete

By Oscar Duckworth

If asked, could you accurately explain why the choice of slump is so important to a wet-mix shotcrete material's hardened properties?

Many current slump specifications are derived from historical beliefs that may no longer be valid. It is widely accepted that slump is a rough measure of concrete consistency - a general term meaning fluidity or stiffness. Using slump to describe an important characteristic of concrete's plastic properties dates back nearly a century.

In the 1920s, Duff Abrams, a young engineer, proved that a plastic concrete mixture's consistency, from the addition of water, had a strong influence on the development of its strength and other hardened properties.

Initially known as the Abrams Cone test, the slump test was created to correlate a mixture's consistency, to a uniform numerical value. At a time when concrete was simply a mixture of Portland cement, water, and aggregates, it became evident that allowing a higher slump could diminish hardened strength. The slump test and correlating numerical value system was quickly adopted as one of the most commonly specified values of a then modern reinforced concrete industry. "Abrams Law:" *Concrete strength development is inversely proportionate to the water content of the mixture*, was coined. Abrams Law remains a primary design parameter for nearly all concrete produced today.

Historically, project specifications determined the allowable slump that could be used for specific concrete placement operations. Since a higher slump was a potential indicator of lower concrete strengths, specifying a slump range was an important tool to help prevent the placement of low strength concrete. An increase of slump, from using excessive water added during batching, or by workers in the field, was (at the time) a major cause of low-quality concrete.

If asked, could you accurately explain why the choice of slump is so important to a wet-mix shotcrete material's hardened properties?

Beginning with the initial patent by Edward W Scripture Jr for a primitive water-reducing admixture in 1934, US patent 2,081,642 described a thick dispersing liquor derived from waste sulphite pulp, added to concrete so that the material will flow more readily. Unknown to Mr. Scripture his patent for a chemical admixture would forever change how we place concrete.

With continuous admixture advancements, especially water-reducing admixtures, the innovations of the last 90 years have dramatically increased the strength and durability of concrete by eliminating the use of water as the primary means to alter the material's plastic consistency. Modern admixture technology can now provide nearly any slump without changing the mixture's water content (w/cm ratio). Because of this, today's admixtures have greatly diminished the choice of slump as having a meaningful relationship to a mixture's strength development.

Nowhere in the concrete Industry is the choice of slump more critical than with shotcrete. Seemingly minor variations in placement slump can affect shotcrete's hardened properties in very major ways. The nozzleman's control of slump is one of the most important concrete mixture characteristics (if not the most important) that can influence the in-place quality. The importance of slump control may not be well understood by those not intimately familiar with the shotcrete process. The need for precise control of slump is no longer due to water content's correlation to strength development, rather it is due to the slump's critical, but largely unseen role of flowability and consolidation.

SHOTCRETE IS A UNIQUE PLACEMENT METHOD FOR CONCRETE

Shotcrete differs substantially from other concrete placement methods in how the material is consolidated. Since proper consolidation is critical to the strength and durability of any reinforced concrete element, consolidation is an essential component of placement. Generally, conventional concrete is placed in a process requiring two individual steps. First, concrete material is placed into a form utilizing generally accepted methods to prevent excessive segregation. Following placement, consolidation, using mechanical vibration or other means is an essential second step.

Mechanical vibration, utilizing the correct pace, equipment, and methodology, is a necessary and well proven method to achieve acceptable consolidation during conventional placement. Shotcrete, however, does not utilize the second step of consolidation through vibration. Shotcrete must be placed and properly consolidated within a nearly instantaneous single high velocity placement step. Because of this, the proper choice of a mixture's consistency is a powerful factor in consolidation success. Unfortunately, few realize the importance of material consistency in this process. The importance of understanding the critical correlation between material consistency to shotcrete consolidation might be compared to the importance of understanding "Abrams Law" to the early days of reinforced concrete.

To understand the immense role shotcrete slump plays in this process, it is important to understand what occurs at the exact moment of placement. To see this, we must look deeply into the nozzle stream, an area that only the nozzleman might ever actually see. It is within this violent agitation zone, where high velocity materials collide with an un-moving receiving surface, where the importance of consistency becomes apparent. A slow-motion analysis of shotcrete placement exposes distinct functions that are ultimately responsible for shotcrete consolidation success. Concrete enters the nozzle as a homogeneous mixture, but becomes both diffused and rapidly accelerated by powerful opposing forces within the nozzle body. The mixture's components will not exit the nozzle as a concrete mixture, but more akin to a shotgun blast pattern of thousands of individuals, unconsolidated paste and aggregate particles moving within a focused, high velocity stream. (Fig. 1).

Fig. 1: Modern nozzle designs diffuse and accelerate the incoming mixture into thousands of individual particles moving within a high velocity nozzle stream.

Upon impact, each particle will behave differently. Some of the larger particles may strike the receiving surface and ricochet or rebound away rather than stick to the surface. However, the mixture's most cohesive component, the paste, tends to stick and remain in place. As a paste layer begins to thicken at the receiving surface, incoming particles begin to collide with other particles trapped within the puddle. Strong agitations, especially those caused by the collisions of the larger, heavier aggregates, cause vigorous high frequency oscillations within the impact zone's developing puddle. These temporary, impact-derived oscillations have the same effect on consolidation within the puddle as the oscillations caused by mechanical vibration.

With shotcrete, temporary viscous flow, caused by impact-derived oscillations will be responsible for the consolidation of all materials directly exposed to the high velocity nozzle stream and the consolidation of materials within the shadow areas not directly exposed to the material stream. Unfortunately, if a mixture's paste is excessively stiff, critically important viscous flow within the impact zone's puddle is greatly diminished. Impact-derived viscous flow may properly consolidate areas directly exposed to the strong nozzle stream, but the puddle may lack adequate flow to completely consolidate materials in the shadow areas. With no second consolidation step, un-filled shadow areas will remain as voids. (Fig. 2)

Fig. 2: This core specimen's major flaw is evidence of inadequate flow during placement.

To a degree, nozzle orientation, and higher velocity can increase impact-derived oscillations and viscous flow within the shadow areas somewhat but will not be sufficient to overcome an excessively stiff paste that lacks flowability. It is important to understand that the placement of excessively stiff mixtures must be avoided due to its strong negative affect on full encapsulation of embedded reinforcing and consolidation quality. A skilled nozzleman must "see" the material flow readily into shadow areas and watch for important visual cues to help maintain the material's proper consistency as placement occurs. Within any given reinforcement configuration, there is a suitable consistency where proper shotcrete placement techniques can achieve acceptable consolidation. For example, more congested elements require a higher slump to achieve proper consolidation (Fig. 3a and 3b). Visual cues, continuously monitored by a skilled nozzleman, rather than a strength-based slump value from a prescriptive specification is the correct way to determine the ideal placement consistency for a given reinforcement configuration.

Fig. 3a & 3b: Different reinforcement configurations require different material consistencies.

Fig. 4: Void beneath reinforcement in saw cut specimen occurred from downward movement.

VISUAL CUES NOZZLEMEN NEED TO KNOW

During placement, a nozzleman must rely on certain visual cues to help maintain an ideal consistency. As impact energy agitates the developing puddle, experienced nozzlemen study the point of impact. If the slump is too high, temporary viscous flow from agitation will cause the puddle to move excessively. The puddle will flow outward and downward excessively, creating a noticeable sag. This visual indicator is plainly visible to the nozzleman. Any attempt to continue, results in more downward flow. Since reinforcements are firmly tied, downward movement of the puddle (sags or sloughs) leads to the potential creation of voids developing beneath horizontally oriented reinforcement bars (Fig. 4). Once created, lacking secondary consolidation, these voids become permanent structural deficiencies within the work. Fortunately, nozzlemen rarely attempt to place excessively fluid mixtures since they lack the cohesive properties required to remain in place or stack on a vertical surface. If the nozzleman attempts to shoot a slump that is too high, placement is either very inefficient, or simply not possible due to the inherent higher flowability of the material. It is the author's observation that shotcrete nozzlemen rarely attempt to place materials with too high of slump for the reasons stated above. Rather, some nozzlemen, especially those less experienced, tend to place materials that are too stiff. There is a natural tendency for less experienced nozzlemen to select a lower slump to help facilitate stacking the materials. Unfortunately, they may be entirely ignoring obvious visual cues within the puddle indicating that proper consolidation may not be occurring due to an improper choice of slump. It is important to understand that the primary goal of an experienced nozzleman is not to stack material to its final height in as few lifts as possible. Rather, it is to place and properly consolidate the materials simultaneously.

RED FLAG VISUAL CUES THAT EVERYONE SHOULD KNOW

Fortunately, using materials at both the right and wrong consistency will always display clear visual cues. If the mixture is too stiff, several easy to identify visual cues immediately become plainly visible not only to the nozzleman, but anyone who can see the placement in progress. To achieve acceptable compaction and consolidation, the mixture must readily flow around all embedded reinforcement. A clear visual cue that the mixture lacks flow is material sticking, or building up on the front of reinforcement within the nozzle stream. Bars should remain clean, with deformations clearly visible until they have become fully encased. If buildup occurs, nozzlemen must immediately stop and make the necessary adjustments to the mixture's consistency. Buildup developing on the face of reinforcements is an obvious visual cue that a mixture is too stiff (Fig. 5).

Other plainly visible cues of excessively stiff material are also evident to those who know what to look for. The receiving surface within shadow areas must fill through viscous flow within the impact zone's puddle. During placement, nozzlemen should train their eyes to study the shadow areas. Watch for complete filling of shadow areas as material is applied. If a visible valley or void line forms (identified as "tracking" by the author) directly behind reinforcements within the shadow area, this is clear evidence that the mixture's paste is too stiff and is not completely flowing into the shadow areas. The nozzleman must stop and adjust the mixture's consistency before continuing (Fig. 6a and 6b).

Fig. 5. Visual evidence of buildup on the reinforcement was ignored by the nozzleman. Note the massive voids that have formed behind the bars.

Fig. 6a. Tracking occurring within the shadow area is easy to see. Tracking behind reinforcements is visual evidence that the mixture is far too stiff.

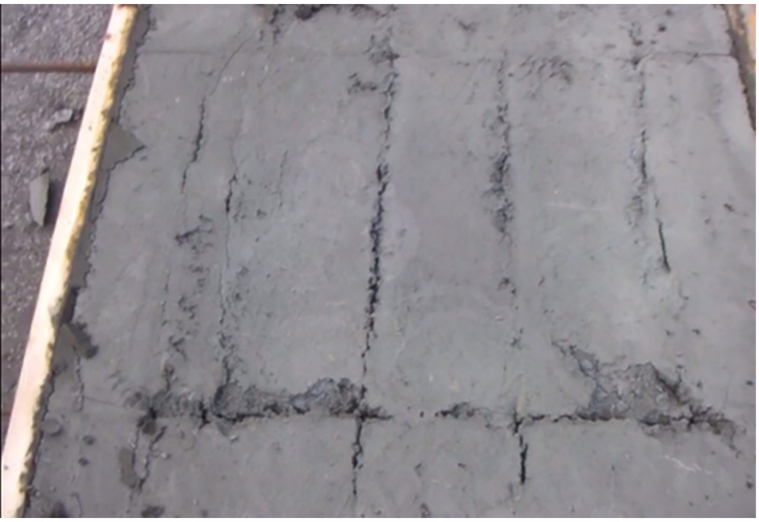

Fig. 6b. Further evidence of tracking visible from the formed side.

The easiest visual cue to proper consistency should be considered as the nozzleman and other workers most basic visual cue that the mixture's consistency is, or is not within the correct range. This easy to identify visible indicator within the freshly applied shotcrete surface will reveal proof of exactly what occurs as high velocity materials collide within the developing puddle. Generally, large and small aggregates make up 70-80% of a shotcrete mixture's volume. The paste is a far smaller fraction of the total volume. Though less abundant, the paste is the mixture's most cohesive element, and adheres readily upon impact. Since actions within the nozzle cause the mixture's aggregate particles to become diffused from the paste, at the moment of impact, the consistency of the paste will have the most influence on the activities of aggregates as they strike the puddle. When the consistency of the paste is correct, the freshly applied shotcrete surface will appear primarily as a glossy or shiny paste layer. Although aggregates are far more plentiful than the paste, very few will be visible on the puddle's surface.

Why would this be the case? A paste with the proper consistency will be sufficiently fluid to allow the fast-moving aggregates to enter and deeply embed within the paste layer leaving a glossy paste surface (Fig. 7). If the paste's consistency lacks fluidity, only the fastest moving aggregates may enter the puddle. Aggregates moving at a slower velocity will only slightly embed or stick to the puddle's surface. Worse,

Fig, 7. The ideal slump allows incoming aggregates to deeply embed within the puddle rather than remaining on the surface.

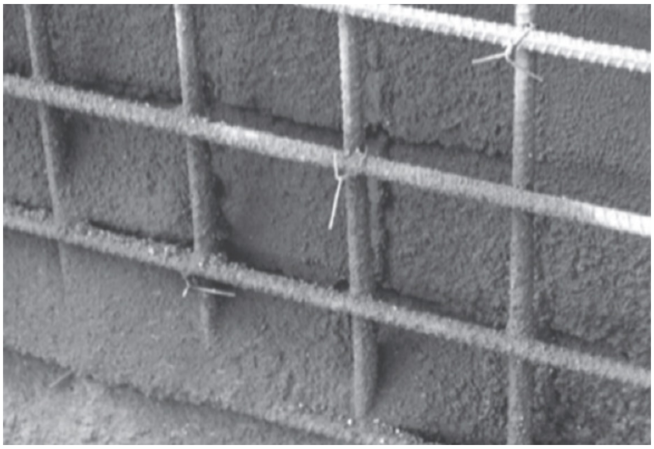

Fig.8. Freshly applied materials with a dull, rocky, or sandy surface is evidence of a mixture that is too stiff.

Fig. 9. Freshly applied materials with few visible aggregates at the surface is the visual indicator of a well-chosen slump.

many incoming aggregates will bounce off the stiff surface, causing excessive rebound. Using a mixture that is too stiff will always result in a surface that appears rocky or sandy rather than glossy.

During application, a dull, sandy, or rocky surface is evidence that the mixture lacks fluidity, and may not reliably flow into shadow areas. A freshly applied shotcrete surface lacking a glossy or shiny paste layer is a powerful visual indicator that temporary viscous flow, caused by impact-derived oscillations is not occurring. Nozzlemen must stop immediately and increase the slump or attaining acceptable consolidation will not be possible (Fig. 8).

Currently, many contract documents still specify a maximum slump or slump range. However, we are starting to see specifications recognize slump's diminished role in strength development and have relaxed or eliminated slump ranges for shotcrete placement. Be aware that some shotcrete specifications citing a slump range as a strength indicator still exist. It is important to remember that proper shotcrete consistency can only be properly chosen through understanding and identifying the important visual cues of the correct slump.

NOZZLEMAN CHECKLIST:

- Important visual cues help the Nozzleman select the correct placement consistency.
- Remember, YOU are in charge of the proper selection of slump.
- Study the impact area's puddle during placement.
- Visually validate that materials are flowing into shadow areas.
- Monitor the area behind the reinforcements for signs of tracking.
- Stop and immediately increase the slump if materials build upon the face of reinforcements.
- Work within a slump range that results in a glossy paste surface (not dull, sandy, or rocky) on the puddle.
- A glossy paste surface is evidence that the paste is both sufficiently fluid to allow the aggregate particles to embed, and flows into the shadow areas.

ACI Certified Nozzleman ***Oscar Duckworth*** *is an ASA and American Concrete Institute (ACI) member with over 25,000 hours of nozzle time. He has worked as a nozzleman on over 2500 projects. Duckworth is currently an ACI Examiner for the wet- and dry-mix processes. He was a former member of ASA's Board and is Chair of ASA's Education & Safety Committee. He continues to work as a shotcrete consultant and certified nozzleman.*

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Temporary High Initial Air Content Wet Process Shotcrete

By Mark Jolin, Ph.D. and Denis Beaupré, Ph.D.

The placement of high strength wet-mix shotcrete is sometimes complicated by the compromise required between obtaining suitable pumpability and shootability of the mixture. On one hand, we need a relatively fluid concrete that will be easy to pump, and on the other hand want a stiff in-place material that does not sag or slough on the wall. Most of the time the simple solutions is to add a set accelerator at the nozzle. Alternatively, the contractor can apply the shotcrete in thin layers and arrange the application schedule so as to allow sufficient time for initial stiffening of the in-place material to take place before the next layer of shotcrete is added. However, due to the stringent quality requirements for shotcrete repairs exposed to freezing and thawing cycles and deicer salts and the potentially negative effect of accelerators, an alternative was sought to allow wet-mix shotcrete to be applied in relatively thick layers of about 4 to 6 inches (100 to 150 mm) without the use of set accelerators.

This is when the Temporary High Initial Air Content concept appeared. It was developed by Denis Beaupré during his doctoral research work in 1994. The Temporary High Initial Air content concept is a clever and simple system by which the fluidity of the fresh wet-mix shotcrete is increased to meet the pumpability requirements by introducing a large amount of entrained air bubble into the mixture to increase fluidity instead of relying solely on water reducers. The "trick" is that during the pumping, and particularly during the shooting processes, a large mount of air is lost due to compaction effect, thus increasing the shootability (ability of the shotcrete to stick and not slough) of the shotcrete (Figure 1). This air loss upon impact on the shooting surface is often referred to as a "slump-killing" effect. This method of shotcrete production has been used in a number of shotcrete construction projects in the province of Quebec with great success for the past three years, and in at least one underground mine in Northern Quebec.

Figure 1: Schematic of Temporary High Initial Air Content

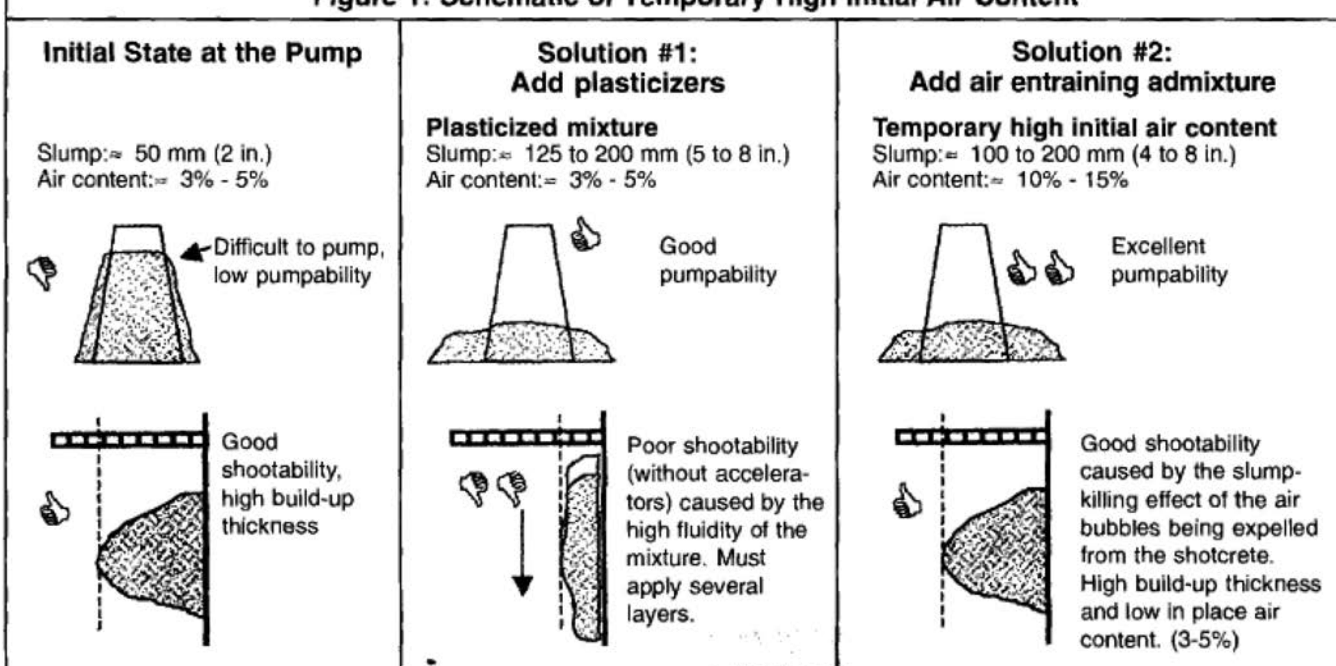

Table 1: Typical wet-mix shotcrete compostion using *Temporary High Initial Air Content concept.*

	Quantity for 1 m^3	1 c.y.
Cement	400 kg	882 lb
Silica Fume	40 kg	88 lb
Sand	1110 kg	2448 lb
Course aggregate (max 10 mm) (3/8 in.)	460 kg	1014 lb
Water	180 kg	397 oz
Water reducer	1500 ml	53 oz
Superplasticizer	5000 ml	176 oz
Air entraining admixture	2500 ml	88 oz

Table 2: Example of test results on the mix described in Table 1.

Slump before pumping	220 mm (8 ¾ in.)
Air content of fresh concrete before pumping	17 %
Air content of hardened in-place concrete	5.3%
Compressive strength	48 MPa (6960 psi)

(This mix was actually shot at the Webster parking structure in Sherbrooke (Quebec, Canada).

The technical aspects of this concept are simple. Instead of adjusting the amount of plasticizer (normal or high-range water reducers and super-plasticizers) to produce 3 to 5 inch (75 to 100 mm) slump at the pump, the admixture dosage is reduced so as to produce a 1 to 2 inch (25 to 55 mm) slump. The air-entraining admixture is then added to produce the slump required for pumping, typically between 4 1/2 inches and 8 inches (120 to 200 mm). The slump-killing effect only works if there is a high initial air content at the pump. Values of around 10% to 15% are typically used, although values as high as 20% have been used. Since this high air content will go down to 4$ to 6% in the in-place shotcrete due to the compacting effect, the negative effect of high air content on the compressive strength is not a factor.

The added benefit of this system is that the residual air content in the in-place shotcrete typically results in an air void system (spacing factor and specific surface). That provides good freeze-thaw durability and resistance to deicing salt scaling in the hardened in-place shotcrete.

The next time you have a wet-mix shotcrete project, why not try the high initial air content method? Air entraining admixtures are typically much cheaper than superplasticizers or accelorators and you might just be pleasantly surprised at how well the "slump-killing" effect works.

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Why Bonding Compounds are Not Recommended with Shotcrete

The Question of Bonding Agents and Shotcrete.

By Ted W. Sofis

Back when I first joined ASA, the question of bonding compounds with shotcrete came up. As a shotcrete contractor for over 40 years, I had experienced all the problems you can imagine in trying to follow specifications where the use of a bonding agent was required with a shotcrete installation. ASA is made up of a wide range of people in the shotcrete industry, including engineers, contractors, manufacturers, and suppliers, and we all agreed on something. When the question was asked, the response was overwhelming with nearly universal agreement among the ASA membership that use of bonding compounds with shotcrete was actually detrimental to achieving a good bond to a properly prepared substrate. I was not a lone voice in the wilderness.

With a good shotcrete repair, the deteriorated concrete is removed back to sound material, the concrete surface and existing reinforcing is either sand- or waterblasted to clean off scale from the reinforcing bars and create a textured profile on the concrete, the mesh or reinforcing is installed, and the repair area is washed with air and water to clean off any loose particulates and wet the concrete surface to create a saturated surface-dry (SSD) condition prior to the shotcrete placement. SSD refers to a surface that is wet without any standing water. The reason for wetting the concrete prior to placing the shotcrete is to create a better bond. A dry concrete substrate will draw the moisture from the newly placed shotcrete, possibly leaving an inadequately hydrated material at the point of contact between the existing concrete and the shotcrete repair. For this reason, wetting the repair area prior to shotcreting is an important step.

With good surface preparation and gunning practices, shotcrete provides an excellent bond to the existing substrate

The dry process of shotcrete being gunned on a pier can provide a better bond without using bonding compounds. The nozzleman is filling in the corners first and working toward the middle of the repair area so he doesn't trap rebound in the corners

When shotcrete impacts the hard concrete surface, a greater percentage of aggregate rebounds from the surface, leaving a thin layer of more cement-rich paste at the interface between the existing concrete and the new shotcrete. As the shotcrete material builds on itself in its plastic state, the rebound of the aggregate decreases. The velocity of the shotcrete process drives the new material in place, creating an excellent bond with the existing substrate. The use of a bonding compound interferes with this process and in many cases actually creates a barrier or bond breaker.

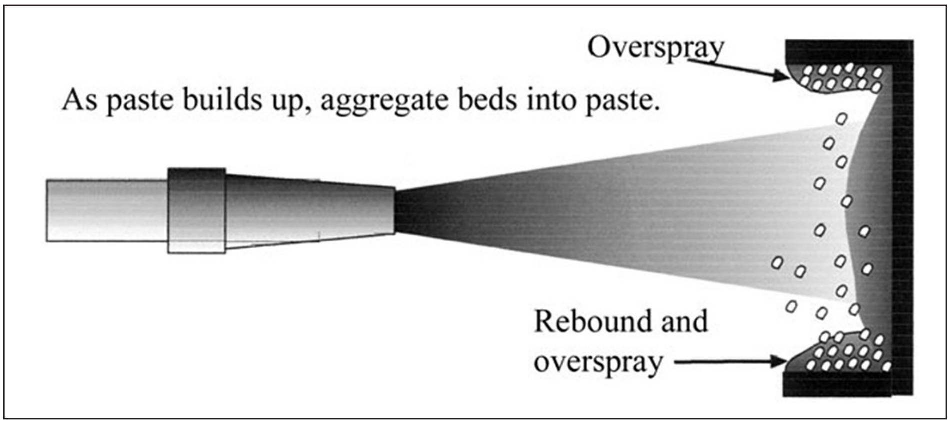
In addition, there are other problems with bonding compounds. With shotcrete, the rebound and overspray will stick to the adjacent areas where a bounding compound has

The top of this industrial sump wall is gunned in place using dry-process shotcrete. The shotcrete process provides an excellent natural bond to the substrate without using bonding compounds. In many cases, bonding compounds are detrimental to achieving a good bond with shotcrete

Shotcrete is gunned at high velocity onto the receiving surface. On initial impact, a larger percentage of aggregate rebounds from the surface, leaving a thin layer of cement paste at the interface of the new shotcrete and the substrate

been applied. Rebound is a cement-poor, aggregate-rich, improperly hydrated by-product of the shotcrete process and is not the material that you want to have at the point of contact. You cannot wash or blow off the rebound and overspray from areas and mesh where bonding compound has been applied. Using a blowpipe to remove rebound will actually cause more unacceptable material to stick to the adjacent areas where the bonding agent has been applied. Also, because shotcrete is sprayed in place gradually across a repair area and isn't cast all at once like a concrete pour, the working time of a bonding compound becomes an issue. If shotcrete isn't placed while the bonding compound is still tacky, the bonding compound becomes a bond breaker. Unless the timing between the application of the bonding compound and the shotcrete is just right, some of the repair areas where the bonding compound has been applied may have hardened by the time the shotcrete is placed. Establishing the "open time" of a bonding agent in place is very difficult to gauge and then coordinate with shotcrete placement.

In summation, when you use bonding compounds with shotcrete, you increase the risk of interfering with the excellent bond produced naturally with the shotcrete process. Rebound and overspray can easily stick to the fresh bonding compound in areas adjacent to the shotcrete placement, which will reduce the bond of subsequently placed shotcrete, creating a high probability that sections of the repair will actually have a bond breaker from the hardened bonding compound. If I've learned anything in my 40 years of gunning, it's that the simpler you can keep things in the field, the more likely you will end up with a good result.



On its initial contact, more aggregate rebounds off the receiving surface, leaving a thin layer of cement paste at the interface between the existing concrete and the shotcrete. The material begins to build on the cushion of plastic material. The velocity of the shotcrete process drives the material in place, creating an excellent bond with the existing substrate.

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

Bond Strength of Shotcrete Repair

By Denis Beaupré, Ph.D.

A good concrete or shotcrete repair must possess three prime char acteristics: 1) the repair material must be durable in an aggressive environment, 2) the repair must be well bonded to the substrate and 3) the repair must be as crack free as possible to efficiently protect any embedded steel reinforcement from corroding.

This article deals only with the second issue: the bond strength of the repair. Before dis cussing bond strength of shotcrete, it may be helpful to look at bond strength of concrete repairs.

In 1956 Felt wrote:

" ...it became apparent that factors influencing bond of new and old concrete were not easily isolated and controlled. The most important factor was the condition of the old surface-its cleanness, roughness and strength or soundness. If the surface was clean, slightly rough and free of weak outer skin, good bond was generally obtained, otherwise relatively poor bond was obtained." (1)

In l 988, our understanding of shotcrete bond strength was much the same as it was for concrete in 1956. Very little information was available concerning the parameters that influence the long term bond strength of shotcrete, particularly the influence of mixture composition and surface preparation. In 1987, Schrader and Kaden reported that the bond between shotcrete and an old concrete surface is generally very good, due to the shotcrete compaction process and the normally low water/cement ratio of this material, particularly for dry-mix shotcrete (2). It is most probable that the phenomenon of rebound plays a more important role than compaction or mixture composition on bond strength than is recognized. When shotcrete starts impacting on the receiving surface only the cement paste sticks to the surface. The other components rebound until a sufficient thickness of paste is built up. A well-compacted layer of low water/cement ratio Portland cement paste is thus formed at the interface between the old concrete and new shotcrete layer.

This paper summarizes the results of a study on the influence of surface preparation and mixture composition on long term bond strength of shotcrete repairs. This paper also presents the results of a new study, carried out in 1998, on the influence of multi-layer applications on shotcrete interlayer bond strength.

BOND STRENGTH OF SHOTCRETE REPAIRS

In a study carried out by Laval University in 1988 (3), many pull-out tests (over 700) were performed to evaluate the capacity of different shotcrete mix tures to produce an acceptable and durable bond to concrete. A secondary objective of this study was to evaluate the influence of surface preparation on shotcrete bond strength. Twenty-one different concrete slabs were cast, cured and allowed to dry for one year. Then several different methods of surface preparation were used to prepare the slabs: sandblasting, jackhammering, jackhammering followed by sandblasting, grinding, and hydro-milling. Following this, slabs were covered with a thin layer of shotcrete. Six dry-mix and four wet-mix shotcrete mixtures of different compositions were used (some mixtures contained silica fume, latex, steel fibers, high early strength cement, or a combinations of some of these variables). All these mixtures were comprised of good quality shotcrete.

Pull-out tests were performed to evaluate the repair bond strength. A 3 ¼ in. (95 mm) diameter core was drilled with the cut extending beyond the bonded inte1face into the original

Figure 1. Pull out test set-up.

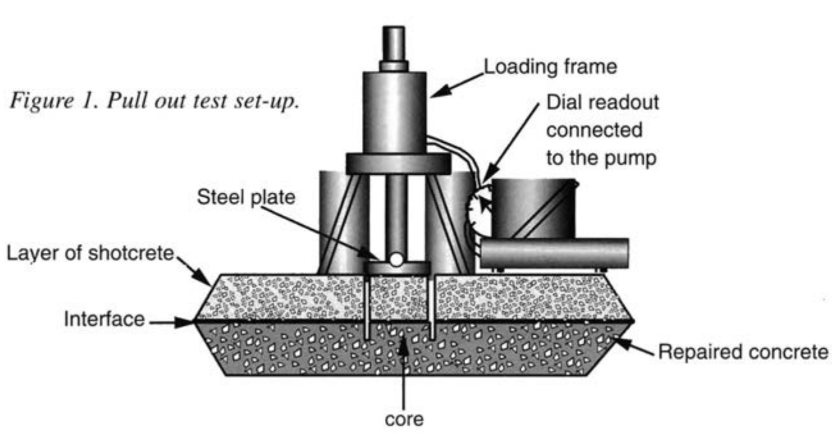


Table 1. Summary of repair bond strength in MPa.

Type of shotcrete	Hydromilling	Sandblasting	Grinding	Jackhammer	Jackhammer + Sandblasting
Dry-Mix	1.6*	2.0	0.2	1.3	1.7
Dry-Mix + silica fume + fibers	2.0	2.3	0.8	1.1	1.9
Wet-Mix	1.6	n/a	n/a	n/a	n/a

*average from tests at 2 and 6 months

substrate concrete. A circular steel plate was attached to the top of the unbroken core by means of a fast set ting epoxy. The test sample was then placed on the testing mechanism and a tensile force applied until failure occured. A minimum of six pull-out tests were per formed at the ages of two and six months for each panel tested.

The results of these tests are grouped and summarized in Table 1. This data is now included in the ACI 506 Guide to Shotcrete. Reference 3 of this paper lists further details of in dividual test results. Each result presented in Table 1 is the average of at least 12 pull-out tests (6 tests at two months and 6 tests at six months).

Apart from the improvement in bond strength evident from the combined use of fibers and silica fume, statistical analysis revealed no significant in fluence of the mixture compositions on the bonding strength obtained for a given surface preparation. However, the type of surface preparation had a significant influence on the bond strength of the shotcrete repair.

The highest bond strength was obtained with sandblasted surfaces. While this is not a very practical method for removal of much concrete, it was a very effective method to improve bond strength of shotcrete to concrete. The next highest bond strengths were obtained with surfaces prepared by hydro-milling, or by jackhammering followed by sandblasting. Jackhammering alone did not seem to produce sufficient bond strength because it left a great deal of unsound cracked particles that weakened the interface. Ground surfaces produced very poor results compared to other preparation techniques.

Hydro-milling seems to have the advantage of removing the damaged concrete, leaving the surface clean without weakening the surface layer of the old concrete. It is fast, efficient, and requires less labor than other methods. Chipping with jack hammers can potentially weaken the surface, but in this case, this phenomenon was not significant. Low mass hammers (15 kg/33 lb.) were carefully used, and sandblasting further helped clean the surfaces by removing some of the residual fractured concrete particles. These two methods of concrete surface preparation are presently the only ones accepted by the Quebec Department of Transport for concrete or shotcrete repairs.

Study on Multi-Layer Shotcrete Bond The bond characteristic of shotcrete is an important issue for the engineer because it has important implications for repair durability. It can have practical implications for the shotcrete contractor because the quality of surface preparation, which is a costly operation, can make the difference between good and bad shotcrete bond. Sometimes, contractors need to place shotcrete in more than one layer. Engineers, seeing bond between layers as a potential source of trouble, and not knowing the best way to accomplish this bond, are sometimes reluctant to allow the placing of shotcrete in more than one layer. The one-layer operation can sometimes cause logistics problems for overhead application: when a thick layer of shotcrete is placed overhead, there is a risk of "fresh decohesion" (delamination) (Figure 2) during the finishing operation even if the shotcrete does not actually fall from the surface. When decohesion is detected after the shotcrete has set, the contractor must then remove the unsound shotcrete and reapply new shotcrete.

In order to obtain data on this issue, the Industrial Chair on Shotcrete and Concrete Repair at Laval University has undertaken a series of tests on the multi-layer bond strength of shotcrete. The results presented in this section are the results of the first phase test program.

During the study, twelve concrete base slabs were coated with two layers of shotcrete. The first layer was applied to a sand blasted concrete surface and produced excellent bonding characteristics. That layer was finished in different ways: 1) no finish, 2) scratched with a steel trowel (but not finished), 3) scratched and finished with a wood trowel, and 4) roughened with a broom. Half of each panel was coated with a curing compound, either by spray or by using a brush. The second half of the panel of shotcrete was either water-cured or left ot dry. After different periods of waiting (4 hours, 1 day and 28 days) the second layer of shotcrete was applied and finished with a wood trowel. Pull-out tests were performed 28 days after placing of the second layer of shotcrete.

Figure 2 shows the geometry of the sample used for this study. Table 2 summarizes the results of the bond pull-out tests for the half panel made without cur ing compound. From Table 2 it can be seen that, for the waiting period and

Figure 2. Pull-off test for multi-layer shotcrete.

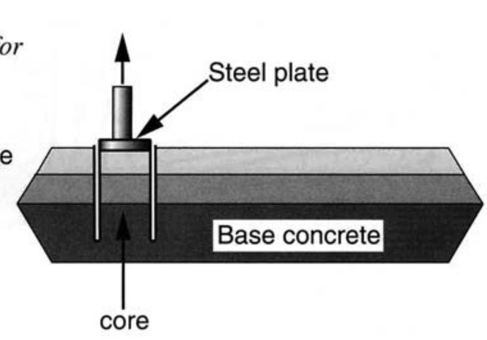


Table 2. Multi-layer bond strength in MPa.

	Type of finish between layers (results with no curing compound)			
Time	None	Scratch	Scratch + Wood	Roughen with Broom
4 hours	2.1	1.8	2.1	1.9
1 day	n/a	2.1*	2.1	n/a
28 days	n/a	1.8	n/a	2.0

*average of 8 tests instead of 4 tests

Conditions	Average Bond Strength
No curing (from Table 2)	2.0 MPa
Curing Compound	1.2 MPa
One layer (no joint)	2.4 MPa

Table 3. Average bond strength.

the types of finish studied, there is no significant influence of these parameters on bond strength. The average bond strength results from Table 2 is (190 psi) 2.0 MPa.

Table 3 compares the average test results from Table 2 with the corresponding average bond strength results for the curing compound condition and for the single shotcrete layer condition. One can see that there is little reduction in bond strength when placing shotcrete in more than one layer if curing compound is not used; however, there can be significant reduction, in the order of 50%, if curing compound is used. The results presented in Table 3 were obtained without removing the curing compound before the application of the second layer of shotcrete. However, if the curing compound was removed with efficient sand blasting, the bond strength would probably be similar to the results from the first study, i.e. be as good as a single layer shotcrete application. For technical and practical reasons the author does not recommend using curing compounds between layers, even if the waiting period before applying the second layer is long.

CONCLUSIONS AND RECOMMENDATIONS

The test results described in this paper indicate that the bonding achieved between good quality shotcrete mixtures and concrete surfaces prepared by hydro-milling or chipping with light jack hammers, followed by sandblasting, is generally strong and durable. The other types of concrete removal (grinding, chipping with jackhammers without sandblasting) resulted in either lower bonding strengths or a reduction in bonding strength overtime (see reference 3 for more information on bond durability). No significant differences were observed between the bond strength of dry or wet process shotcrete applied on hydro-milled surfaces.

With respect to the multi-layer bond strength of shotcrete, the presence of shotcrete/shotcrete interfaces does not seem to create a large reduction in shotcrete quality in terms of mechanical bond if no curing compound is used. However, in saturated conditions and in the presence of freezing and thawing, engineering practice typically requires that the bond interface should be contained between the base concrete and the outermost reinforcing layer.

ACKNOWLEDGEMENTS

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REFERENCES:

I. Felt, E.J., "Resurfacing and Patching Concrete Pavement with Bonded Concrete," Proceedings of Highway Research Board, 1956, pp. 444-479.

2. Schrader, E. and Kaden, R., "Durability of Shotcrete,"(SP-100-57), Detroit, ACI SP- I 00: Concrete Durability, 1987, pp. 1071-1102.

3. Talbot, C., Beaupre, D., Gendreau, M., Lamontagne A., and Pigeon, M. "Durabilite des reparations en beton projete (Durability of shotcrete repairs)," Report submitted to the Department of Transportation of Quebec, 1992, 86 p.

Conversion factors: I MPa = 145 psi

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Surface Preparation for Shotcrete Repairs

By Denis Beaupré, Ph.D.

Surface preparation is an important element of the repair process, either with shotcrete or cast-in-place concrete. It covers a large scope including concrete removal, saturation of the substrate, use of bonding agents (rare with shotcrete), cleaning of the surface, etc. These operations are influenced by the local conditions (surface position: vertical or overhead, the presence of reinforcement) and are very important for both the short and long term bond strength and thus the repair integrity. When all steps involved in surface preparation are considered, it is obvious that these operations represent a large part of the repair cost, and may reach up to 50% of the total repair cost. For this reason, it is important not to neglect surface preparation.

The subject of surface preparation is not fully understood. The information presented in this technical tip is based on my experience in shotcrete research and practice over the past fifteen years. It should be seen as my personal understanding of the subject at the present time. What follows could change as research progresses.

There are several "schools-of-thought" regarding surface preparation. Some subjects are still being discussed and constitute the hot issues. Among the most controversial are: the use of a bonding agent, saturation of the substrate, and preparation between layers of shotcrete. Concrete removal is a less contentious subject.

CONCRETE REMOVAL

The most common way to remove concrete has been the use of a pneumatic chipping hammer. In the past ten years, the use of hydro milling has become increasingly popular. A summary of the results from a ten year old study on shotcrete bonding (Talbot et al, 1994) was presented in the second issue of Shotcrete (Vol. 1, No. 2, May 1999). In terms of concrete removal, hydro milling was found to be very effective as was the use of a chipping hammer, followed by sandblasting. It was also shown that the use of sandblasting alone (when no demolition was needed) helped produce an excellent and durable bond. Usually, properly applied shotcrete produces a bond in excess of 1.5 MPa (around 200 psi) in direct tension.

USE OF A BONDING AGENT

Bonding agents are not typically used in shotcrete repair. It might be interesting to discuss why not. The reason is simple: while shotcreting, the first layer of material that sticks to the substrate surface is a fully consolidated layer of a relatively low water/cement ratio material. Moreover, this layer is always followed by the application of the bulk of the shotcrete repair material, without having time to set. This is almost the perfect description of how bonding agents (at least cement based ones) should perform. Therefore, shotcrete usually bonds completely to a substrate without the requirement of a bonding agent.

DEGREE OF SATURATION

The necessary degree of saturation of the substrate or the eternal question: wet or dry? (not the shotcrete process but the state of the receiving surface) is not an easy one. To answer, many agencies have different requirements on how long the surface must be kept wet prior to shooting. Strictly

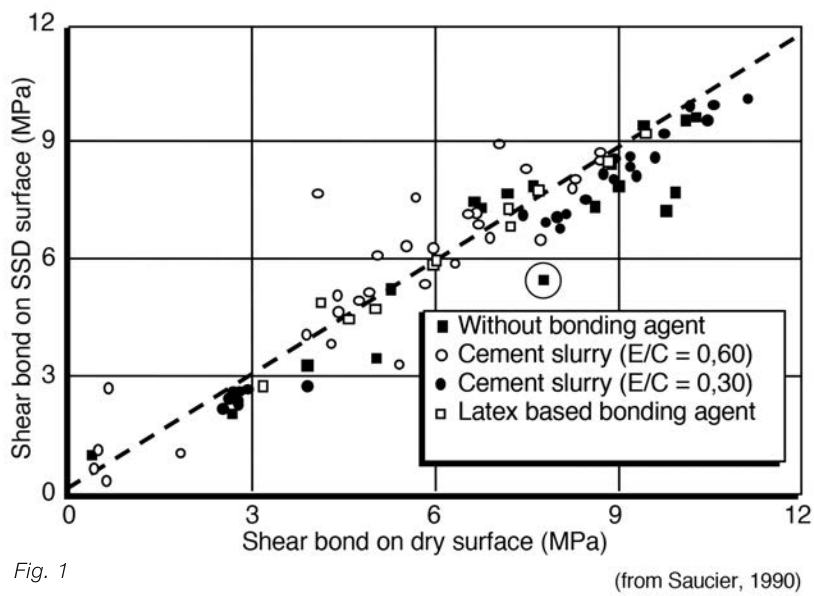

Fig. 1

from the point of developing a good bond, the following figure shows data from shear bond tests performed on two different moisture conditions; dry and saturated surface dry (SSD). Each dot represents the bond strength of particular repairs for both conditions. Since there are more dots above than below the dotted line, it means that "on average" the bond strength is higher for the repairs performed on the dry surface than on the SSD surface.

From this data, it appears that the degree of saturation is not very critical and in most cases a dry surface is better. However, one must keep in mind that these repairs have been performed on a clean surface in the laboratory. In practice, the reason for requiring a pre-dampened surface (or SSD) is that is insures that the surface has been "cleaned" before shooting. Of course, no free water should be left on the surface: air blowing is always necessary subsequent to wetting the surface. Excess water on the surface results in a high water/cement materials ratio, and hence reduction in bond strength at the critical interface between the substrate and shotcrete.

Conclusions

The shotcrete process inherently provides a good bond. However, poor bonds have been observed when shooting on non-sandblasted surfaces, on dusty surfaces, or on curing compounds. If these situations are avoided, and if the shotcrete is not allowed to sag or debond in the green state (common when shooting too thick of layers on overhead surfaces), good bond results should be achieved.

If specifications calling for bond strengths higher than 2 MPa (around 300 psi) are encountered, it might be wise to use silica fume; greater surface preparation will only help a little. Specifiers should be warned that requiring more than 1.5 MPa direct tensile bond strength is very demanding. This should only be done for special purposes and not as a general requirement. If safety is a concern, use mechanical anchors and wire mesh; do not specify higher bond strengths for it is too risky.

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The History of Shotcrete

Part III of a Three Part Series

By George D. Yoggy

There is little question that the history of shotcrete is fascinating and useful. The invention, the evolution, the successes, the "crash," and the struggle to recover through parts of the century is somewhat unique to the shotcrete process. How shotcrete is viewed in today's construction industry, however, is very serious and very important. What of this recovery from the seeming demise of a construction method that achieved such success for so many years and then wandered away from the technical foundation and discipline of application?

The properties and performance of gunite were carefully established, meticulously tested, documented, and communicated to the industry. This sprayed-concrete process was widely accepted around the world and produced cost-effective results in countless applications. In some times and places, the technology was lost, abused, and ignored as we wandered away from the path of the original process. But some changes in the modern era have brought improvement, advancement, and new opportunities for the shotcrete process. Several new ideas were part of the midlife crisis, but the most important change may have come with the development of those new machines of the '60s and '70s and the material possibilities that accompanied them.

The invention of the rotor-type continuous-feed gun for dry-mix material provided two distinct advantages over the standard double tanks that dominated the process for more than half a century: higher production and large aggregate mixtures were now achievable as norms. The door had been opened for more flexibility in sprayed concrete applications, as well as for more versatility in concrete mixture design. Spraying wet concrete would soon become a part of the process.

Chemistry began to play a role, and confusion over terminology quickly set in. The term "shotcrete" was used in a railroad publication some years previously to describe changing mixtures and methods. Shotcrete was used by some to describe mixtures with large aggregate (up to 5/8 in. [16 mm]) rather than gunite, which was considered to be sand and cement only. Others described the new wet method as shotcrete to differentiate from the long-established gunite system. Finally, ACI stepped in to end the confusion and define pneumatically applied concrete or mortar as "shotcrete, including the wet-mix method and the dry-mix method," and a new era for the industry really had its beginning. Some would argue that this was the start of the real period of decline—confusion perhaps, but not really a step backward, other than the fact that many choices allowed many results, and some were not very good, which is often a price paid for progress. We could spend a great deal of time reviewing results; however, that should be done at another time. Traditional gunite applications continued in a very healthy way in many areas, even though they were questioned in others. The fact is, however, that shotcrete became a renewed construction method by the late '70s with nearly endless opportunities and a few rough edges. Higher-volume output now kept pace with other advances in equipment and materials that provided for growth in construction. Advances in concrete technology that started to make great strides in the '70s also contributed to advancements in the shotcrete

The introduction of the Rotary Gun in 1957 paved the way for large aggregate and high-volume shotcrete process, especially the wet-mix method. This culminated with the development of the swing-tube concrete pump that really made wet-mix shotcrete practical. The industry was changed forever. Almost anything could now be done with shotcrete, and it seemed that almost everyone was trying it. Was the industry about to take another step backward? The answer here could be “almost.” Fortunately, it’s probably “not quite.”

High-volume wet-mix shotcrete with large aggregate is evident in the texture of the material already placed

The early years of large aggregate, high-output, dry-mix shotcrete set the pace for the soon-to-be developed wet-mix method, especially in underground construction. Shotcrete was proving to be invaluable as a method for supporting rock and earth excavations in tunnel and mine construction. High volumes placed in many underground projects (50,000 yd^3 [38,000 m^3] was common for a tunnel job) provided countless opportunities to study the performance of both materials and equipment, leading to still more innovations and improvements. Since a large portion of this concrete placed underground was overhead, chemical accelerators were introduced to provide for fast set and early strength development. Chemical compatibility and in-place performance became important considerations, and even more was learned about this method of placing concrete as laboratory work and pre-job testing accompanied more applications. Progress continued at a rapid pace. Shotcrete was beginning to be considered “technical” again by many in the industry, because it is. The evolution of concrete pumps in the general construction market contributed to the development of machines that were also efficient for spraying wet-mix concrete, and the world has never looked back, except to learn from those who went before. Concrete technology, including chemical admixtures and supplementary cementing materials such as silica fume and fiber reinforcement, has become an integral part of the process for both wet- and dry-mix shotcrete. The bar has been raised considerably for the equipment and materials producers and suppliers, and for the knowledge and skill required of today’s shotcreter.

Automated wet-mix shotcrete for a geotech application

Truly, shotcrete was in a recovery mode during these redevelopment years of the ‘70s and indeed, has gone beyond many expectations. Sprayed concrete (as it is known in many parts of the world) has not only achieved technical status, it sometimes reaches exotic levels of mixture technology and construction performance. The underground proving ground provided for the development of many product and equipment innovations such as fiber reinforcement, silica fume, high-performance admixtures, and mobile robotic equipment. Pumpable concrete made equipment perform more efficiently, and more efficient equipment made concrete applications in vertical and overhead arenas more effective and economical. Each improvement led to

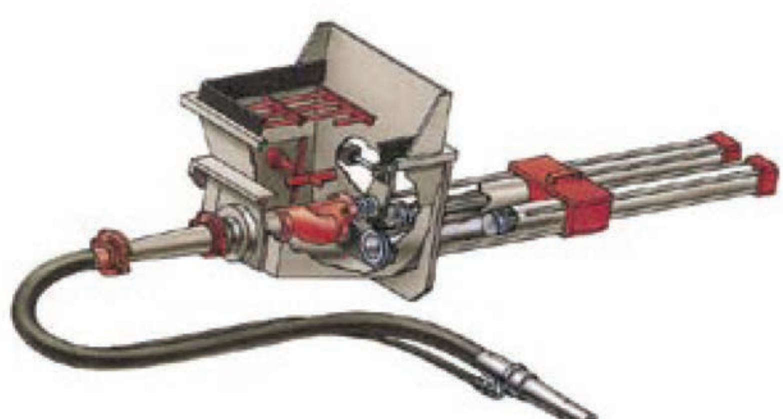
Tunnel construction provided a proving ground for new materials and equipment

another as challenges were met in many aspects of construction. It is quite safe to say that more progress and change has taken place in the shotcrete process during the last 15 years than in the previous 75 years of its history.

Where are we today? Are the skills no longer with us? Is shotcrete relegated to cosmetic classification and shunned by the engineer? Have we abandoned the gunite process that has had such a long and successful history and turned to wet shotcrete as a panacea? Hardly!

Wet machines are available for projects ranging from "dental work" to high-production, heavy construction applications. And the double tank is still produced. Mixtures can be designed, packaged, and delivered to meet any need—site-batched, in a bag, or in a truck. Ironically, the success of wet-mix shotcrete has been achieved by combining modern material and equipment technologies with the patented basics of the original invention. Sound, well-graded materials combined as a concrete for placement at high velocity to achieve sufficient compaction to perform at levels above similar cast materials. And the neat thing is, you can place it upside-down if you like. Today, it is possible to achieve similar results in all phases of shotcrete construction with both wet- and dry-mix shotcrete methods. Properly understood, they are a screwdriver and a wrench. Which one is better? Depends on the task. What's really important is education, training, information sharing, and understanding. Shotcrete has become a sophisticated method of placing concrete and requires credentials suited to the task.

The industry has not only recovered but has also taken giant steps forward. We are no longer forced to defend our position with only the pages of ACI 506. The engineering community is embracing shotcrete as the viable structural construction method it has always been and is meeting modern building challenges with effective designs. Documentation and information describing successful design and construction experiences are abundant. Standards, specifications, and guidelines are available from industry sources from leading nations around the world to provide the owner, designer, and constructor with the information necessary to deliver a proper project. Contractors are becoming educated, trained, and certified to accepted levels of practice for today's requirements. Organizations such as ASA provide the opportunity for the industry to meet and exchange experiences and information vital to the health and growth of the process.



Development of the swing tube concrete pump made wet-mix shotcrete practical

The basics from Akeley, the direction from Collier, and the hard work and dedication of many who followed still apply. Quality components, high velocity application, proper technique, controlled water-cement ratio, clear understanding of the process, sound concrete practice, and discipline blended with modern materials and equipment allows nearly endless opportunities.

Recovery, complete!

Future, bright!

MESSAGE FROM FORMER ASA PUBLICATIONS COMMITTEE CHAIR MARC JOLIN

There is certainly more to the story, and many of the details of each year or decade can shed light on why we do things the way we do, what works, and what doesn't. We continue to share those experiences through our association with one another in this diverse and growing industry each day that we do work, and through the recording and reporting of what is experienced. Get involved! Let us know what you're doing. These pages allow for the sharing of experiences—yours!

George D. Yoggy *has been directly involved in shotcrete and concrete applications for underground, heavy construction, and repair of concrete structures for more than 40 years. From 1967 to 1986, Mr. Yoggy owned and operated Concrete Equipment Corp. and Shotcrete Plus, Inc., a business engaged in the design, manufacture, and supply of equipment for ground support,shotcreting, and concrete placing systems in the North American tunneling, repair, and mining industry. In 1986, the company was acquired by Master Builders, Inc., and he established the Underground Construction group for MBT Americas.*

As a director for MBT Americas, Mr. Yoggy is responsible for developing and managing the supply of products, equipment, and services for shotcrete applications in the underground and general construction markets. He has international experience in shotcrete for ground support technology employing NATM and similar techniques developed in Switzerland and Austria, as well as shotcrete for repair and refractory applications.

Mr. Yoggy serves on various committees, including ACI and ASTM Shotcrete and Certification Committees, and is a member of the Board of Directors of ASA and President Elect of the American Underground Construction Association. He continues to be an active participant and respected leader in industry initiatives.

{Editor's Note: George Yoggy passed away on March 27, 2018. Sadly, as our Association matures and grows, we lose those insightful individuals who saw the need for an association like ASA in 1998. We truly stand on the shoulders of giants like George Yoggy.]

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