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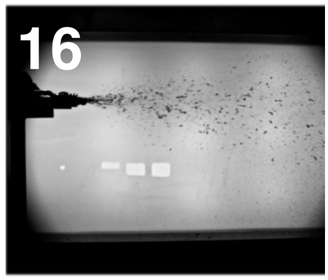
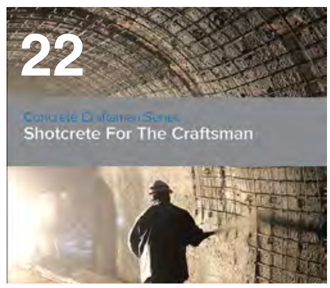
FEATURES





DEPARTMENTS

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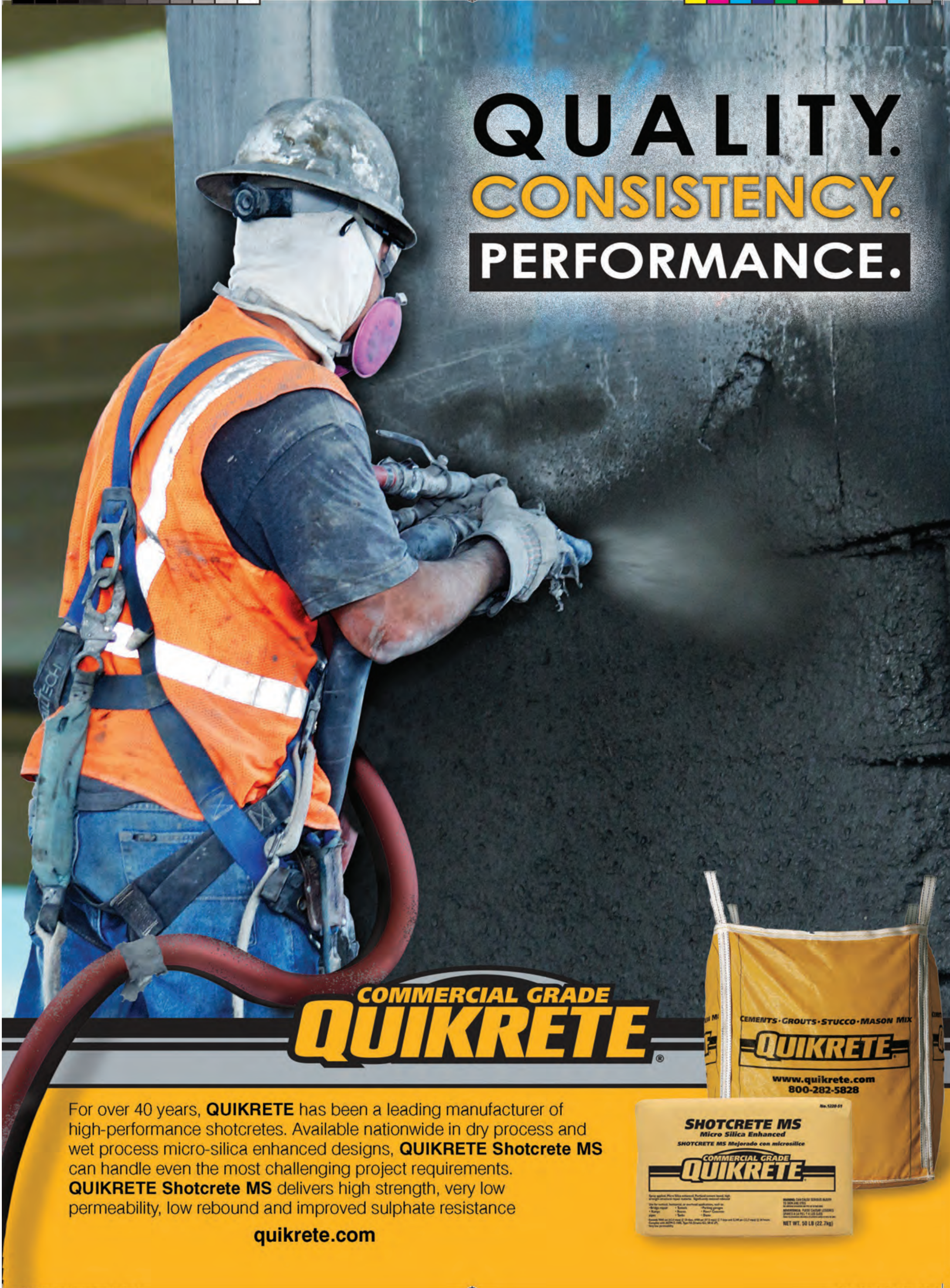
The opinions expressed in *Shotcrete* are those of the authors and do not necessarily represent the position of the editors or the American Shotcrete Association.

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

DEPARTMENTS (continued)

2023 Honorable Mention Project, the Neville Island Bridge | Coraopolis, PA: Installing Shotcrete from a barge in the main channel ofthe Ohio River.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The Only Constant is Change

By Oscar Duckworth

The American Shotcrete Association was formally established in 1998. In its first 25 years, our Association experienced rapid change in both membership and size, and firmly established its position as an industry leader. Over the years, leaders like Yoggy, Tatnall, Beaupre, Isaak, Dufour, Zynda, Drakeley, Schallom, Totten, Sofis, von der Hofen, Jolin, and Hanskat have influenced change through their significant personal efforts within the Association. The involvement of these contributing members was the guiding force for this rapid change. Inferior workmanship in the past and a general lack of understanding regarding shotcrete placement with specifiers, building officials, and the engineering community were, at the time, powerful obstacles to the use of shotcrete.

> The only constant is change."
>
> – Heraclitis

These contributing members helped quell these opinions and pushed the shotcrete industry to new heights by doing the following:

- Helping create a global information resource—*Shotcrete* magazine and the Shotcrete.org website.
- Establishing formal certification criteria— ACI Shotcreter (originally: Nozzleman) Certification.
- Generating education and safety programs.
- Developing the Shotcrete Inspector Program.
- Promoting immense industry outreach and resultant credibility

Ultimately the diligent work of ASA brought shotcrete placement onto an even playing field with form-and pour within concrete industry codes, standards, and specifications.

The diligent efforts of past leaders and contributing members of our Association are responsible for this change—one that we all are currently benefiting from.

Again, we are in a period of rapid change. Shotcrete placement is routinely used to build complex elements that I could not have imagined possible 20 years ago. The pictures below showcase just how far shotcrete has come.

This change is driven by the following:

- Better equipment
- Greater acceptance of the shotcrete process
- Advanced placement techniques
- Optimized mixture designs
- Supplementary consolidation with precise vibration
- Significant improvements in remotely manipulated equipment

These changes will continue to be driven by a new generation of leaders. If you are 50 and under, YOU will be responsible for all future changes. But like before, these changes will only come through involvement, through an investment of time, through attempting new ideas, and through failure.

> "It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change."
>
> – Charles Darwin

At the end of my term as President, I will have been involved with the ASA for 25 Years. It's your turn to step up, to become involved, and to influence change.

If we are to grow as an Association, and flourish as an industry, it will be because of your involvement—you, the future leaders of ASA!

The Power of Membership and Marketing

By Jason Myers

One of the many great things discussed at our 2024 ASA convention was the assignment of strategic goals and priorities to different ASA committees. One item that became apparent was the tremendous overlap of goals between the Membership and Marketing committees. It made sense then, for the near future, that these committees should be combined to facilitate their similar direction and vision without duplication of volunteer effort. Over the history of ASA, committees have combined and separated to further the efforts of the Association, it appears the need to combine these committees is appropriate at this time.

As we refine the strategic goals for this “new” ASA Committee, it is important to look at how Membership and Marketing interact. A key element of Marketing is showing how and why you need the product that is being sold. In this case, why is ASA membership essential to growing the use and quality of shotcrete in the concrete construction industry?

So often, companies sit on the sidelines and wonder why other companies develop a competitive edge. I submit that involvement in professional societies and learning from each other plays a major role. This year at ASA’s annual convention, participants were able to enhance their understanding of how shotcrete can be done better. It was great to hear the different professional seminars given at ASA’s convention and learn about what others are doing and how they are growing the shotcrete industry. Equally beneficial was sitting around over a meal and glass of wine or two and talking with others about the difficulties and trials we are dealing with on our various projects. Some companies don’t participate because they are concerned that they might be giving away company secrets or that their competitors might find out what they do. In reality, we are all doing very similar work. No one really has deep company secrets, and most of the companies and people that you are talking to are in other parts of the country or even the world and will never be direct competitors. By not participating, you are actually giving yourself a competitive disadvantage.

> “Participation and involvement in an organization such as ASA lends credibility to both you and your company.”
>
> – Monica Rourke, Mapei - UTT

An area of ASA's Membership and Marketing Committee's current focus is the pool industry. This is a very large segment of the shotcrete industry and would most benefit from attention to education and quality shotcrete placement. Quality is the heart of the ASA message. When correctly placed, shotcrete's versatility, adaptability, and efficiency enhance concrete's inherent properties. When shotcrete is placed successfully, we all succeed. The damage caused by a poor reputation takes decades to build back trust. The pool industry is one sector that isn't well regulated and has seen many inexperienced companies attempt to fill a demand, especially during the pandemic, when the demand for residential pools far outpaced the supply of quality shotcrete contractors.

ASA is working to increase available education for the pool owners, designers, and builders. Raising the bar for performance on the minimum requirements, expectations, and installation procedures so that all pools can be installed successfully. Numerous new shotcrete pool contractors attended this year's ASA convention, specifically to receive comprehensive education from the one-day Quality Shotcrete for Pool Builders seminar and the series of pool seminars presented during the convention. These contractors decided not to sit on the sidelines but instead invested a couple of days for enhanced shotcrete education. Why? To gain an advantage over their competitors who didn't make the same effort to learn, and so in doing continue to make the same mistakes over and over again. They recognized that an investment in ASA Membership supported opportunities to learn and grow their business.

The ASA Membership and Marketing Committee (M&MC) wants to serve its members better. Why one joins an organization is not necessarily the same reason why one stays. Companies will often join for monetary reasons, e.g. discounts for shotcreter (formerly nozzleman) certification sessions. Why they stay delves into a less quantifiable value. ASA's M&MC will launch several initiatives to better understand what members value and how ASA can better serve our membership while furthering quality shotcrete placement. A mentorship program to connect newer members with more seasoned members is one of those initiatives.

Membership combined with active involvement gains the most value. It is one thing to get *Shotcrete* magazine and look at the pretty pictures, while it is entirely different to be involved in writing the articles and helping our committees develop position statements. We are all looking to improve ourselves and the shotcrete industry, but it is entirely different to sit back and wait for standards and codes to appear rather than contribute to its creation. It's hard to pin down direct *leads* resulting from my ASA membership, but I know of numerous projects that I have picked up by being associated with and involved in ASA. I know of several projects that I won from knowledge gained at ASA events and sessions; a couple projects that I obtained from the competitive advantage of being an ASA Qualified Shotcrete Contractor; and numerous projects improved upon because of the knowledge that has been learned at ASA events. By understanding what ASA can provide my company and what ASA does for the shotcrete industry I know that my company has benefited from its membership and further that our involvement has helped advance the shotcrete industry as a whole.

As we start this new round of strategic goals for our M&MC, it is essential to be involved. By educating yourself and getting other firms to join, it raises the bar for all of us. Improving the shotcrete industry turns out to be the best marketing strategy for the industry and our companies. By actively using our membership, we profit most from it and can even help steer future dividends. By using shotcrete placement to the best industry standards, we all continue to promote shotcrete for future shotcrete projects and provide income for all of us. Being an active ASA member is one of the best marketing tools out there, but it all starts with you being a member.

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You Can Be an Award Winner!

An Overview of our ASA Outstanding Shotcrete Project Awards Program

By Charles S. Hanskat, P.E., F.ACI, F.ASCE, ASA Executive Director

This year marks the 20th Annual Outstanding Shotcrete Awards program, a staple in the shotcrete industry highlighting creativity, quality, and innovation in the shotcrete process. Engineers and owners have accepted shotcrete's flexibility to create high-quality concrete structures while improving efficiency, enhanced sustainability, and reduced resource costs. The American Shotcrete Association's (ASA) awards program recognizes and promotes global shotcrete utilization by recognizing winning projects from around the world.

Striving to continually improve the submission application and ultimately draw more awareness to the program, major updates to the application process have been implemented this year to aid in increasing participation and improving the content for judges to review.

IMPROVING THE APPLICATION PROCESS

To streamline participation submissions, a task group comprising judges, past award winners, and staff collaborated to refine the application process. The result is an updated application designed to guide the submitter in better describing their shotcrete project(s) in-depth.

For prospective applicants, it's essential to provide details to present a clear narrative demonstrating how shotcrete was instrumental to your design or construction solutions. What story does your project tell? How can it inspire others to consider shotcrete to tackle design or construction challenges that are "outside the box." This is an opportunity to brag about shotcrete's role in the success of your project.

Pictures are important; however, remember that details regarding the obstacles and challenges faced, as well as the successes, will separate your submission from the crowd. Describing innovative shotcrete methods, unique applications, time and access constraints, material and equipment constraints and how your team overcame these hurdles all contribute to highlighting shotcrete's role in your outstanding project. Show the judges how your project exemplifies the benefits of shotcrete placement and perhaps lead skeptics to consider it on their next project.

Consider the following tips to boost your project's chances of being a "winner":

- Review the application questions before making the submittal to ensure all required information is readily available. Also, reach out to other members of your project team to gather expanded input.
- Provide accurate contact information, particularly for the main contact person, who will receive updates on the project's status and award details if selected.
- Include comprehensive project team details, including roles such as Shotcrete Contractor, Architect/Engineer, Materials Supplier, Equipment Manufacturer, General Contractor, and any other relevant contributors.
- In the body of your descriptions, do not include any company or individual names to facilitate blind judging.
- Submit photos showcasing the project's progression, ideally including before, during, and after images to offer judges a complete perspective. Providing captions for each image will also help the judges better evaluate what the image is detailing.
- Include any prior accolades or features for the project from other organizations or industry publications.

PROJECT AWARDS AWARENESS

Awareness of ASA's awards program not only highlights and celebrates excellence within the shotcrete industry but also provides a great marketing opportunity for the submitter and project team. You join an exclusive circle of projects that demonstrate in finished concrete what shotcrete placement can accomplish. It allows others to consider the possibilities where conventional form-and-pour applications fall short.

As the construction industry evolves, it is essential to underscore the benefits shotcrete placement affords, including creativity, flexibility, efficiency, cost-effectiveness, and sustainability. By showcasing successful projects worldwide, we demonstrate the versatility and adaptability of shotcrete placement in various construction contexts, encouraging its adoption in diverse applications. ASA's awards program is not only about celebrating achievements but also about driving positive change and advancing the adoption of shotcrete as a whole. Your outstanding work expands the options available to architects, engineers, and owners to realize their designs in high-quality, durable concrete with shotcrete placement. Highlighting your work opens doors for shotcrete's acceptance and continual advancement in the concrete construction world.

We look forward to your submission! Application is available now and closes October 1, 2024. Visit www.shotcrete.org/awards to start your submission today!

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.

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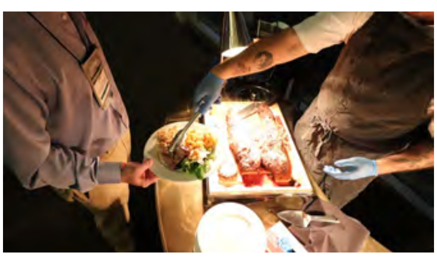

A Study on Low-Velocity Sprayed Mortars

By Christine Poulin and Marc Jolin

INTRODUCTION

One of the most significant challenges in civil engineering is the rehabilitation and repair of deteriorated reinforced concrete infrastructure. Many techniques exist to ensure reliable and safe structural repairs, and one of them, known for its unique high-velocity pneumatic placement process, is shotcrete. Thanks to this high-velocity process, shotcrete generates substantial material consolidation to ensure proper reinforcement encapsulation and excellent adhesion to the repaired surface. It commonly removes the need for complex formwork while allowing for rapid execution of work, resulting in significant economic advantages. Shotcrete is the key to many complex construction scenarios, such as curved and irregular architectural shapes, repairs with little or no downtime, infrastructure with narrow and difficult access, and it even works in remote areas.

A different pneumatic placement technique that seems to have grown in popularity in recent years for structural repairs is low-velocity sprayed mortar (LVSM). This process, initially used in the construction and renovation fields to replace hand-applied mortar with a trowel, differs from shotcrete by the very low velocity of its particles during spraying. The system uses a small pump that pushes the fully mixed material at the nozzle, spraying it at low velocity onto a receiving surface. This technique is used for several types of application, such as surface covering, aesthetic renovations, coating for fire protection, sandwich panels, and more recently, concrete repairs. However, LVSM applicability to structural repairs remains to be demonstrated due to the lack of technical information in the industry. The presence of reinforcing bars and the relatively thicker applications in most structural repairs may present serious challenges for the quality of LVSM placement.

While shotcrete relies on high-particle velocity to provide in-place material consolidation to meet structural repair requirements, LVSM relies instead on a slightly adapted material rheology to allow consolidation with minimal energy. Although the LVSM process represents a spray-on approach to placing thin layers of repair material, its ability to generate adequate structural repair must be investigated, particularly from the standpoint of reinforcement encapsulation and substrate adhesion.

Based on an extensive research and development project conducted in the Shotcrete Laboratory at Université Laval entitled "Low-Velocity Sprayed Mortar and Shotcrete: what are the differences?," this article's purpose is to present interesting data about LVSM, including material properties and durability, substrate adhesion, placement technique, rebound, reinforcement encapsulation, and material velocity. (Poulin, 2019).

EQUIPMENT

The International Concrete Repair Institute (ICRI) defines LVSM as "the placement of a repair material by spraying using a low-velocity pump with air added at the nozzle" (ICRI, 2023). Indeed, to achieve low-velocity spraying, the equipment required is essentially a rotor-stator pump with nozzle and hose, a small air compressor, and a mortar mixer, as shown at Fig. 1.

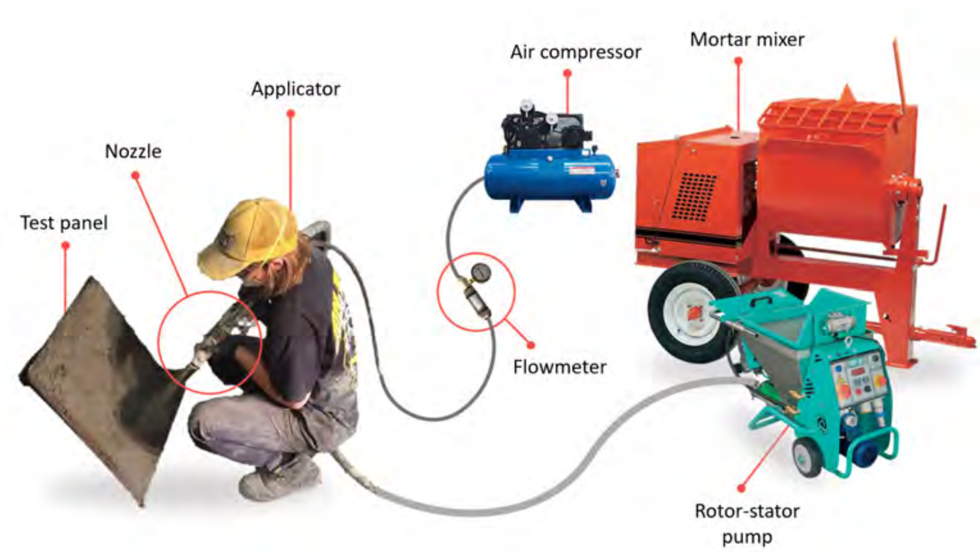

Fig. 1: LVSM system built in the Shotcrete Laboratory.

There is quite a variety of equipment available in the industry for LVSM systems. IMER's Mighty Small 50 pump was chosen for the experiment with a recommended 18 CFM air compressor. A flowmeter system was also included in the compressed air supply line to monitor the airflow during placement.

The selection of an appropriate nozzle along with adequate airflow was found to be the most important set of parameters influencing the overall quality of LVSM placement and the properties of the material in-place. There are different types of nozzles for distinct jobs with the low-velocity process, as shown in Fig. 2a and 2b.

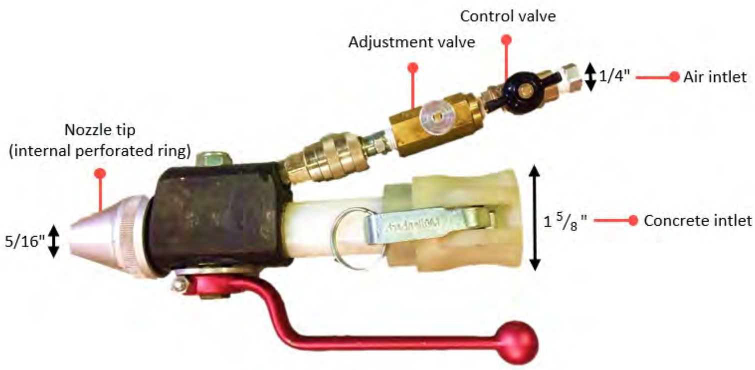

Fig. 2a: LVSM nozzle no. 1 used in the research project.

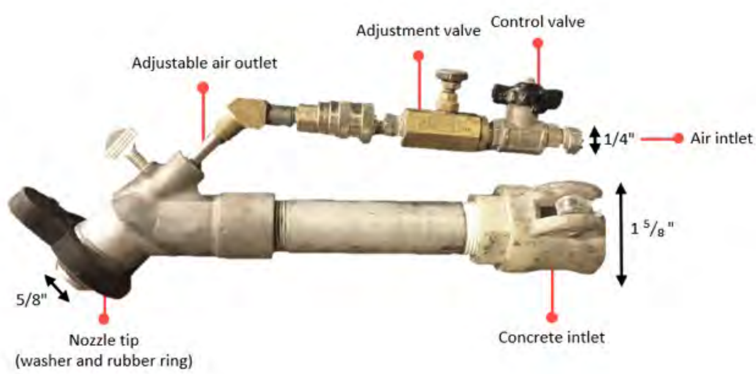

Fig. 2b: LVSM nozzle no. 2 used in the research project.

Both nozzles used for LVSM had different configurations that significantly influenced the sprayed mortar stream. As detailed in Fig. 2a, the tip of nozzle no. 1 includes a perforated ring for air supply, while Figure 2b shows nozzle no. 2, which is frequently used for stucco finishing work, uses only one direct air outlet. These nozzles were modified with an appropriate system of adjustment and control valves for better accuracy when adjusting airflow during the experiment.

The LVSM system selected for this experiment was tested with three repair products specifically designed to be applied by low velocity. The mortar mixes selected were the Planitop 12 SR from MAPEI, the MasterEmaco S 488CI from BASF, and the Tamms Structural Mortar from Euclid Chemical. These pre-packaged mixes were tested by spraying in the laboratory without knowledge of their composition and mixture design. The amounts of water added to the mixes were determined by testing the different dosages recommended by the manufacturers. The water content chosen for each mix was selected for its best response in the pump, going through the nozzle, and during placement of the material.

MATERIAL PROPERTIES AND CHARACTERISTICS

At the Shotcrete Laboratory in *Université Laval*, the results were obtained with samples of sprayed mortars at low velocity. The properties and characteristics for Planitop 12 SR, MasterEmaco S 488CI, and Tamms Structural Mortar were all comparable with both nozzles. Therefore, only the results obtained with Planitop 12 SR are presented in Table 1. For the results on wet-mix shotcrete, the properties and characteristics are based on previous studies conducted on shotcrete and the ACI guide (ACI PRC 506-22, 2022). It should be noted that the properties and characteristics presented for wet-mix shotcrete show what is generally obtained with this process. The results found in the literature for shotcrete are variable and depend considerably on the composition of the concrete mixtures and their consistency.

According to the results presented in Table 1, both shotcrete and LVSM produce very high-quality materials based on the mechanical properties and material durability. Compressive strength, resistance to chloride ion penetration, and resistance to freeze-thaw cycles are excellent with both high and low velocity. Shotcrete does not seem to resist as effectively to the aggressive conditions simulated in the laboratory for the de-icing salt scaling tests, while LVSM shows slightly higher porosity and absorption. Despite these comparisons, the results presented remain excellent for both processes.

Just like for shotcrete, the bond strength tested provides excellent results with LVSM on a concrete substrate with a compressive strength of 32 MPa (4700 psi). For each test performed, the failure patterns of the specimens were found at the substrate. For surface preparation, the concrete substrate was brought to an ICRI CPS-5 and saturated surface dry (SSD) condition prior to spraying the material. Despite limited consolidation velocity, LVSM provides adequate adhesion to the substrate. The composition of the mortar mixes is a definite cause of the excellent ability of the repair material to bond to another substrate. The results shown demonstrate that the LVSM mixture design is of very high-quality and requires very little consolidation energy. However, it must be said a pre-packaged LVSM bag costs about three to four times that of a pre-packaged bag of wet-mix shotcrete.

Besides the excellent mechanical and durability properties, several elements between wet-mix shotcrete and LVSM

Table 1: Comparison between shotcrete and LVSM

Properties and characteristics	Wet-mix shotcrete	LVSM	
		Nozzle no. 1	Nozzle no. 2
Compressive strength at 28 days ASTM C1604 – Shotcrete ASTM C109 – LVSM	28 to 41 MPa and even > 83 MPa (4,000 to 6,000 psi and even > 12,000 psi) (ACI506-22, 2022)	63 MPa* (9,140 PSI) *mortar cubes	61 MPa* (8,850 PSI) *mortar cubes
Resistance to chloride ion penetration – RCPT ASTM C1202	689 to 862 C (using silica fume) (Bolduc, 2009)	735 C	868 C
Freeze and thaw – durability factor ASTM C666-A	97 to 102% (D. R. Morgan et al., 1988)	96%	94%
De-icing salt scaling ASTM C672	0.02 to 3.46 kg/m^2 (Beaupré, 1994)	0.32 kg/m^2	0.27 kg/m^2
Porosity ASTM C642	14 to 17% (ACI506-22, 2022)	18%	22%
Absorption ASTM C642	6 to 8% (ACI506-22, 2022)	9%	11%
Bond strength ASTM C1583	> 1 MPa (145 psi) (ACI506-22, 2022)	> 2.0 MPa (290 psi)	> 2.4 MPa (350 psi)
Spraying technique	Direct the nozzle perpendicular to the surface while rotating the nozzle in a series of small oval or circular patterns. (ACI506-22, 2022)		
Technique for encapsulating reinforcement	Perpendicular to the reinforcing bars at sufficient velocity	Start with nozzle tip pointing behind reinforcing bar and build out to desired thickness*	Impossible
Material thickness – vertical	Up to 200 mm (8 in.) without accelerator	< 50 mm (2 in.)	
Distance of spraying	0.6 to 1.8 m (2 to 6 ft) (ACI506-22, 2022)	0.3 m (1 ft)	
Rebound	10 to 15% (ACI506-22, 2022)	Negligible	
Reinforcement encapsulation**	Feasible: the maximum bar size and steel congestion will be function of mix design, equipment and shotcreter's experience	Very difficult, requires specific procedure. Practically impossible if many or large diameter bars.	Impossible
Spraying velocity – maximum	33 m/s (73.8 mph) (Ginouse & Jolin, 2013)	4.5 m/s (10 mph)	2.6 m/s (5.8 mph)
Air flow rate	200 CFM (Ginouse & Jolin, 2013)	5 CFM	11 CFM

* Material does not flow naturally around the bar; the applicator must adapt the placement pattern accordingly.
** According to an ACI-C660 certified examiner.

are very distinctive. The following sections will focus on the findings with LVSM in terms of placement technique, rebound, reinforcement encapsulation, and velocity.

PLACEMENT TECHNIQUE

LVSM placement technique differs mainly because of the particle velocity sprayed through the nozzle. Despite the attempts in the laboratory, the traditional shotcrete placement techniques could not be imitated by the LVSM. Based on the experiment, when spraying perpendicular to a receiving surface, the distance from the nozzle must be reduced to 0.3 m (1 ft) with a small circular motion. Depending on the mortar mixes, the maximum material thickness in one layer would be less than 50 mm (2 in.) vertically. Otherwise, the fresh material in place has no hold and runs off the surface by gravity.

When encapsulating reinforcing bar, the most effective placement technique identified, especially with nozzle no. 1 (Fig. 2a), is to start with nozzle pointing directly behind the reinforcing bar and build out to desired thickness by spraying the material in successive layers. Due to the low velocity, the material does not flow from the front to the rear of the reinforcing bar, which will leave voids. The efforts needed for full encapsulation of the reinforcing bars with LVSM required a significant amount of time and attention, even under controlled and optimal laboratory conditions.

A certification offered by ACI for shotcreters (formerly called shotcrete nozzleman) ensures a minimum level of workmanship, whereas no certification appears to be available or required for the low velocity mortar spraying process. The results demonstrated that the applicator must adapt to new conditions with LVSM to ensure a good quality of material in-place and limit operating problems during spraying. However, the absence of regulatory documentation surrounding LVSM leaves room for any applicator with or without experience to use LVSM at their convenience without the appropriate knowledge, which can lead to poor quality work.

REBOUND

Unlike shotcrete, which generates significant rebound, it was observed during the experiment that practically no rebound was generated with LVSM. In fact, most of the material adhered to the receiving surface. Following the model developed by Armelin & Banthia (1998), it appears the properties of the freshly applied substrate created by the LVSM and the low kinetic energy of the particles (associated to the low velocities) combine to produce very favorable conditions to drastically reducing rebound. This is an advantage for LVSM. However, even if there is no rebound production, the price of the LVSM material is still much higher than the price of wet-mix shotcrete including rebound, and thus does not provide an economic benefit.

REINFORCEMENT ENCAPSULATION

Inspired by the ACI shotcreter certification (ACI, 2015), reinforcing bar encapsulation tests with LVSM were performed with the placement technique developed in the research laboratory. The conventional certification panel was reduced by half for LVSM testing, and the evaluation of the reinforcing bar encapsulation was performed by an ACI-approved examiner. The results obtained with both LVSM nozzles are shown in Table 2.

Under controlled and optimal laboratory conditions, it was possible with great effort and care to achieve successful reinforcing bar encapsulation at 5 CFM of airflow with the use of nozzle no. 1 (Fig. 2a). However, the results obtained with nozzle no. 2 (Fig. 2b) were poorer and inadmissible in accordance with the regulations of the ACI shotcreter certification program (ACI, 2015).

This demonstration shows that specific conditions must be followed to perform small structural repair with LVSM, such as the use of nozzle no. 1 (Fig. 2a) with a single row of reinforcing bars with full access to the rear. However, under typical field conditions, LVSM might not be suitable as a replacement for shotcrete due to the location and number of reinforcing bars, and the thickness of the repair. Shotcrete

Table 2: LVSM reinforcement encapsulation

Core #	1	2	3	4	5
Nozzle no. 1					
Ranking	1	1	1	1	1
Nozzle no. 2					
Ranking	5	5	5	4	4

remains the only pneumatic placement technique to achieve adequate structural repair of all kinds, which has been ensured by standards, technical guides, and certification programs.

VELOCITY

By using a similar procedure as used before for shotcrete research, the velocity profiles were calculated for the LVSM with nozzle no. 1 and nozzle no. 2. Based on the shape of the spray pattern, the velocities of particles, and the quality of the material being placed, the most efficient results and preferred combination were at 5 CFM with the nozzle no. 1 and at 11 CFM with the nozzle no. 2.

The velocity profile with nozzle no. 1 at 5 CFM was distributed over a vertical distance of approximately 130 mm (5 in.) as presented in Fig. 3a and 3b. At 300 mm (12 in.) from the origin, the maximum particles velocities concentrated in the center of the distribution were reaching 4.5 m/s (15 ft/s), while those present at the periphery of the spray were slower by about 1 m/s (3.3 ft/s) from the center.

Regarding nozzle no. 2: the velocity profile selected at 11 CFM was distributed over a vertical distance of approximately 140 mm (5.5 in.) as presented in Fig. 4a and 4b. With the same distance from the origin, the maximum particles velocities were reaching 2.6 m/s (8.5 ft/s). There was no concentration of maximum speeds at the center of the distribution.

The decrease in velocities generated by the LVSM is very significant compared to the 33 m/s (110 ft/s) at 200 CFM by wet-mix shotcrete presented in the work of Ginouse and Jolin (2013). The velocity reductions created by using LVSM are 86% with nozzle no. 1, and 92% with nozzle no. 2.

Regardless of the level of velocity, the material properties tested during the LVSM experiment always met manufacturer specifications in terms of strength and durability. Consequently, the only criterion for any type of pneumatic process would be the use of sufficient consolidation energy to obtain quality material in-place, whether at high or low velocity. In fact, the energy required to consolidate the material would depend on the velocity threshold dictated by the pneumatic process, the equipment used, the rheology, and the composition of the mixture.

CONCLUSION

The present experiment conducted in *Université Laval* addresses some misconceptions about the uses of LVSM.

Fig. 3a: LVSM particles spray at 5 CFM with nozzle no. 1—recorded image for speed calculation.

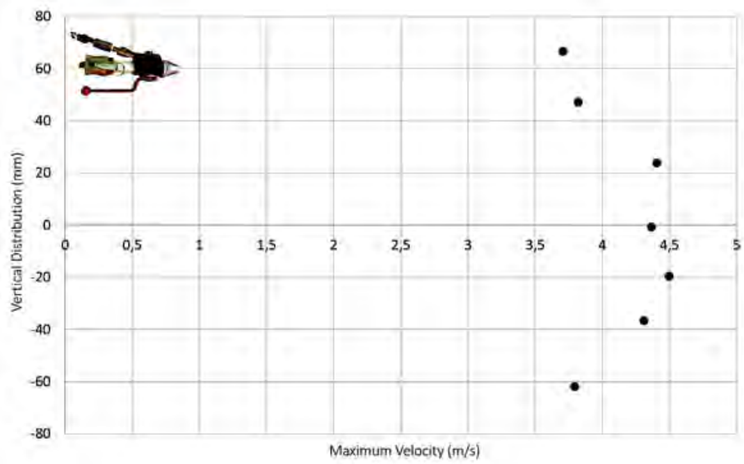

Fig. 3b: LVSM particles spray at 5 CFM with nozzle no. 1—velocity profile.

Fig. 4a: LVSM particles spray at 11 CFM with nozzle no. 2—recorded image for speed calculation.

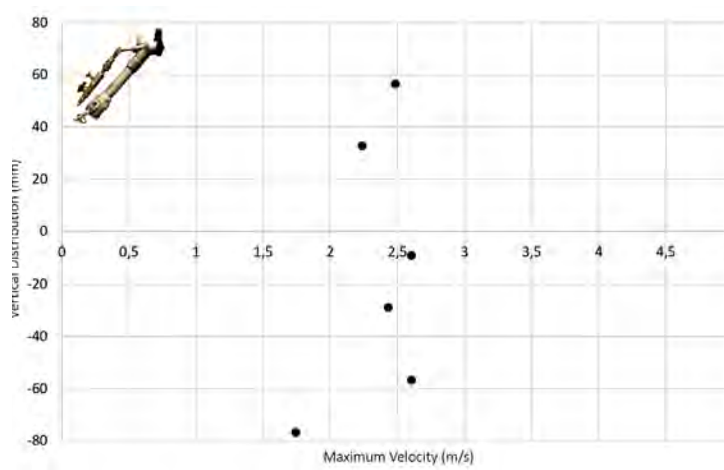

Fig. 4b: LVSM particles spray at 11 CFM with nozzle no. 2—velocity profile.

Indeed, the results shown that LVSM can produce durable works, as is the case with shotcrete. Whether at high or low velocities, sufficient consolidation energy is the key to achieving proper work and obtaining high-quality material. However, where reinforcing bars (or other obstacles) are to be encapsulated under typical field conditions, LVSM is not suitable due to its specific application conditions and poor results obtained during the present experiments. Consequently, shotcrete remains the only pneumatic placement process that can perform adequate structural repairs of all kinds, ensured by standards, technical guides, and certification programs.

Although LVSM should not be used for small structural repair, the advantages from LVSM can be promising for non-structural concrete repair applications, i.e. without reinforcing bar. However, technical support, such as a credible guide and specifications, must be created in the industry to ensure the in-place quality of work. Today LVSM is used by both experienced or inexperienced applicators, which can lead to potential poor-quality repairs.

Finally, LVSM shows that a slightly adapted rheology allows consolidation of the material with minimum energy. Therefore, would it be possible to find a middle ground between the energy required to consolidate material and an optimized rheology to produce shotcrete with low rebound production? The high energy required to consolidate shotcrete is physically demanding and leads to difficult working conditions, especially with the production of rebound. If a right balance between energy and rheology could be found, would shotcrete be more appreciated by all industry players and valued as sustainable for new generations? Research should focus on this aspect and see how to evolve shotcrete for a promising future.

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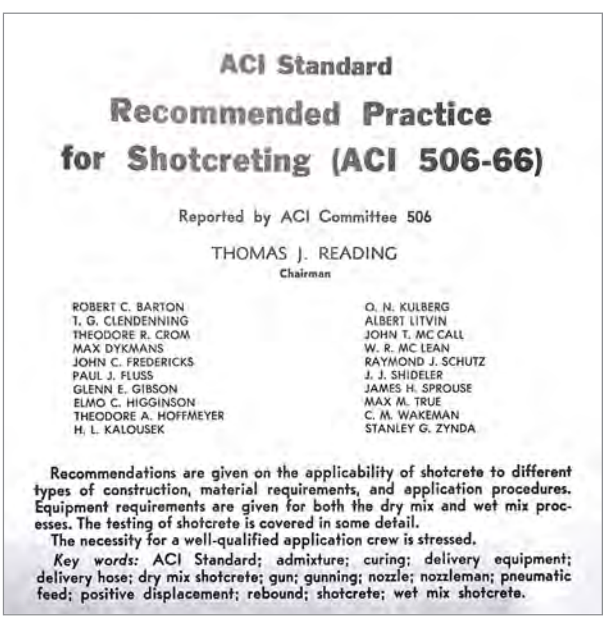
Guide to ACI Shotcrete Documents

By Lars Balck

In 1907 Carl Akeley developed a method of shooting a sand and cement mixture. Early promotion of the sand-cement mixture as "Gunite" by the Cement Gun Company led to use in a variety of concrete applications. By 1950, Gunite was widely adopted and popular because it produced high-strength concrete and allowed for the economical placement of concrete in difficult locations. Gunite (now called dry-mix shotcrete) enjoyed success but also, unfortunately, attracted many contractors who didn't fully understand the materials and process. This lack of knowledge led to many shotcrete projects failing. With the resulting poor reputation many engineers refused to specify shotcrete placement on their projects.

There were no standards or guidance to lead contractors to proper selection of materials, equipment, or placement techniques. The reputation of shotcrete declined and by the late 1940's, concerned shotcrete companies and consulting engineers asked the American Concrete Institute (ACI) to form a committee to provide an authoritative guide. ACI Committee 805 in 1950, prepared the standard "Proposed Recommended Practice for the Application of Mortar by Pneumatic Pressure". This document was the first to use the term "shotcrete" as they stated, "To avoid the cumbersome term 'pneumatically-placed mortar' the word 'shotcrete' is used to refer to this material in the remainder of this report."



ACI Standard

Recommended Practice for Shotcreting (ACI 506-66)

Reported by ACI Committee 506

THOMAS J. READING

Chairman

ROBERT C. BARTON
T. G. CLENDENNING
THEODORE R. CROM
MAX DYKMANS
JOHN C. FREDERICKS
PAUL J. FLUSS
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JAMES H. SPROUSE
MAX M. TRUE
C. M. WAKEMAN
STANLEY G. ZYNDA

Recommendations are given on the applicability of shotcrete to different types of construction, material requirements, and application procedures. Equipment requirements are given for both the dry mix and wet mix processes. The testing of shotcrete is covered in some detail.

The necessity for a well-qualified application crew is stressed.

Key words: ACI Standard; admixture; curing; delivery equipment; delivery hose; dry mix shotcrete; gun; gunning; nozzle; nozzleman; pneumatic feed; positive displacement; rebound; shotcrete; wet mix shotcrete.

Fig. 1

In the 1960's ACI formed Committee 506 to permanently address shotcrete placement. Their first document was titled "ACI Standard 506-66 Recommended Practice for Shotcreting." The members of the first ACI 506 committee are a "Who's Who" of early shotcrete (Fig. 1). The ACI 506-66 document "Recommended Practice" evolved into the "Shotcrete Guide" which is likely the most used shotcrete document today. Since the formation of the ACI 506 committee, many more shotcrete-specific documents have been produced. Below is a brief description of the current ACI 506 shotcrete documents.

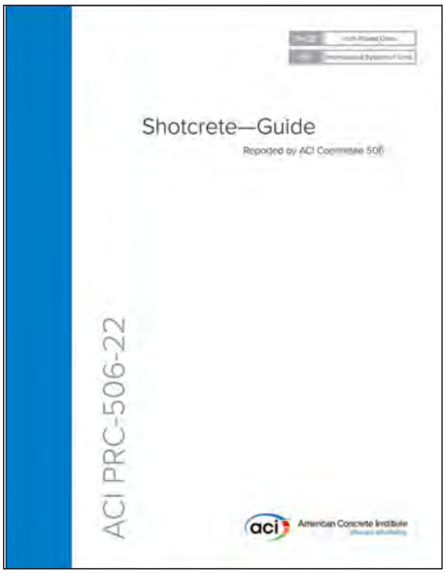
ACI PRC-506-22: SHOTCRETE GUIDE

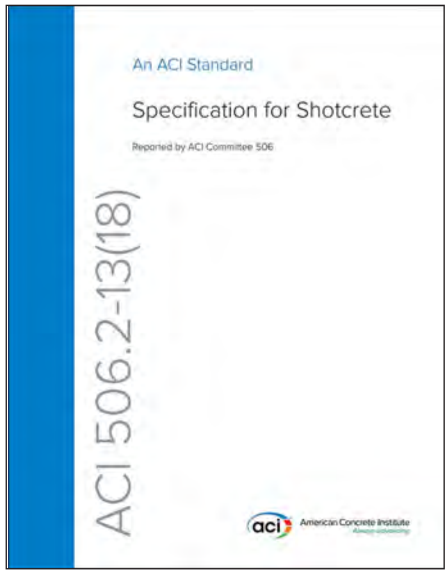
The Shotcrete Guide grew from the committee's first document ACI 506-66. It uses non-mandatory language and serves as a shotcrete primer. For most in the industry, this is the go-to document for those who want to learn what shotcrete was all about. The Shotcrete Guide has been revised many times. The current version was formatted as a companion document to ACI 506.2 Specification for Shotcrete which uses mandatory language. The section numbering between the Specification and the Shotcrete Guide match, so in effect, the Shotcrete Guide serves as a commentary for the Specification. In addition, the Shotcrete Guide has additional content to cover all facets of shotcrete placement, including equipment, application procedures, crew responsibilities, materials, and testing. Anyone wanting to learn about shotcrete should begin by becoming familiar with the Shotcrete Guide. It is also a great resource for those active in shotcreting to keep a copy as a reference.

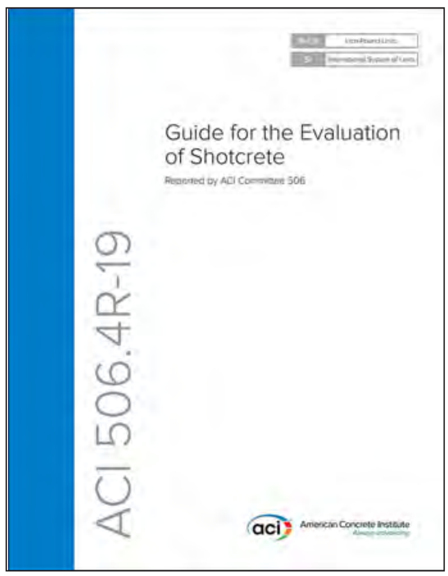
ACI SPEC-506.2-13 SPECIFICATION FOR SHOTCRETE

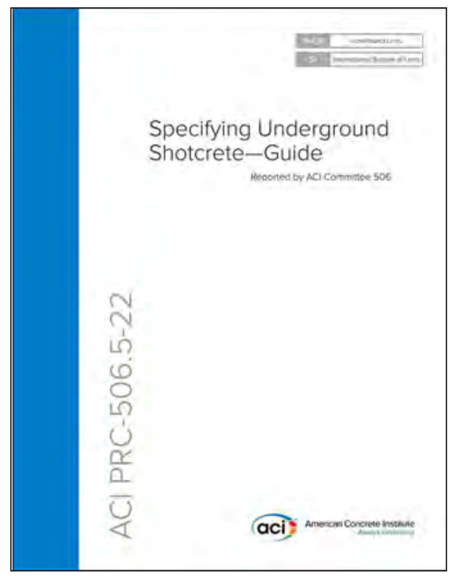
This specification is for contractors. It contains the construction requirements for the application of shotcrete, minimum standards for materials properties, testing and application.

The materials processes, quality control measures and inspections described in the specification should be tested, monitored, or performed as applicable only by individuals holding the appropriate ACI certifications. The mandatory and optional checklists at the back of the Specification will be used by the specifier. Mandatory items should be addressed in the contract documents for specific projects using shotcrete placement. The optional checklist items









should be reviewed by the specifier to determine whether they are applicable to their specific project. With broader adoption of shotcrete placement, we will see more reference to ACI 506.2 in contract documents. Also, ACI SPEC-301-20: Specifications for Concrete Construction, and ACI SPEC-563-18: Specifications for Repair of Concrete in Buildings refer directly to 506.2 for their shotcrete provisions.

ACI PRC-506.1-21: FIBER-REINFORCED SHOTCRETE – GUIDE

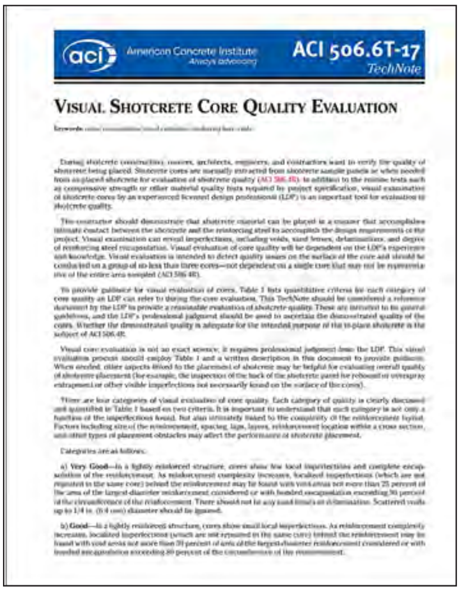
This guide is for anyone involved in fiber-reinforced shotcrete. It describes the technology and applications of fiber-reinforced shotcrete (FRS), focusing on synthetic and steel macrofibers. The guide bridges information between two ACI committees: 506 (Shotcrete) and committee 544 (Fibers). The guide provides proportions of mixtures, application procedures, general performance criteria of FRS and design considerations.

ACI PRC-506.4-19: GUIDE FOR THE EVALUATION OF SHOTCRETE - GUIDE

This guide, as the title explains, presents procedures that can be used to evaluate the quality and properties of shotcrete mixtures and in-place shotcrete. The Guide for Evaluation describes the most relevant test methods applicable to shotcrete along with recommendations for selecting the most appropriate methods and interpreting test results. The guide is divided into 12 chapters, ranging in content from determining mixture proportions to evaluating hardened shotcrete through compressive strength tests or nondestructive testing methods. Efforts have been made not only to present the testing methods available but also to guide the reader on the relevance of each method for a testing program.

ACI PRC-506.5-22: SPECIFYING UNDERGROUND SHOTCRETE – GUIDE

This document provides a guide for owners, designers, specifiers, and inspection organizations developing specifications for projects using shotcrete placement for underground excavation support. The guide specification provides general information for the selection of constituent materials, and methods to proportion shotcrete. Typical methods of batching, mixing, and handling of proportioned shotcrete materials are detailed along with shotcrete placement methods and equipment. The guide briefly discusses the concept of composite ground support—the combination of shotcrete and other support elements used to provide early and effective tunnel support. The guide is not a comprehensive treatise on the design of these systems but is intended to provide sufficient background to understand how the combination and sequencing of ground support elements can influence the performance, application, inspection, and testing of shotcrete.



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ACI 506.6T-17 TechNote

VISUAL SHOTCRETE CORE QUALITY EVALUATION

ACI PRC-506.6-17: VISUAL SHOTCRETE CORE QUALITY EVALUATION – TECHNOTE

This tech note was developed to give a rational basis for owners, architects, engineers, and contractors to verify the quality of shotcrete placement. Shotcrete cores are normally extracted from shotcrete mockup panels or when needed from as-placed shotcrete for evaluation of shotcrete quality (ACI 506.4R). In addition to the routine tests such as compressive strength or other material quality tests required by project specification, visual examination of shotcrete cores by an experienced licensed design professional (LDP) is an important tool for evaluation of shotcrete quality.

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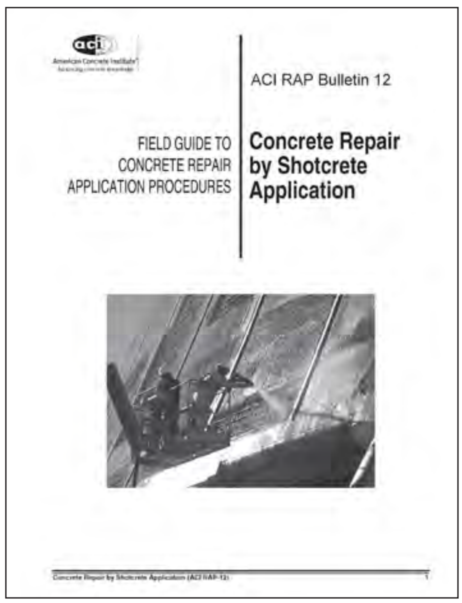
ACI PRC-506.7-23 TechNote

SHOTCRETE PRECONSTRUCTION MOCKUP—TECHNOTE



ACI RAP Bulletin 12

FIELD GUIDE TO CONCRETE REPAIR APPLICATION PROCEDURES

Concrete Repair by Shotcrete Application

ACI PRC-506.7-23: SHOTCRETE PRECONSTRUCTION MOCKUP – TECHNOTE

The phrase "shotcrete test panels" has been used in the industry to cover a variety of uses in the preconstruction and production evaluation of shotcrete placement of concrete. The purpose of this technote is to help the architects and engineers to use the terminology "mockup" and "test panel" to better define their specific requirements on a shotcrete project. The majority of the technote focuses on the use of shotcrete preconstruction mockup panels for evaluating materials, equipment and shotcreter (formerly nozzleman) competence.

ACI PRC-506.X CONSTRUCTION OF POOLS USING SHOTCRETE – GUIDE

This document has not yet been published as of Spring 2024. This document is intended for use by owners and pool builders who are building shotcreted pool shells. It does not include specific design requirements. It does include recommendations for aspects of planning, design, and construction that are needed for quality shotcrete placement with the goal of producing pools that have the long-term durability and serviceability owners should expect. Though other ACI 506 documents, like the Shotcrete Guide cover shotcrete placement in general this document focuses on the specific needs of shotcreted pool shells.

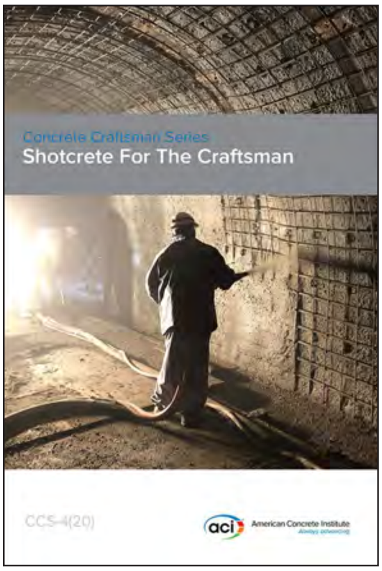
ACI RAP-12 - CONCRETE REPAIR BY SHOTCRETE APPLICATION

The ACI Education Committee has produced a set of field guides to concrete repair application procedures. The RAP documents are freely available from ACI and cover a wide variety of concrete repair topics. RAP-12 provides a short overview of the shotcrete process as typically used to restore structural integrity, increase concrete cover over reinforcement, or both. It addresses the reduced forming requirements and presents another repair tool in the designer's and contractor's tool kits.

SHOTCRETER (FORMERLY NOZZLEMAN) EDUCATION DOCUMENTS

SHOTCRETER CERTIFICATION

Engineers and contractors for years have recognized that the shotcreter has more influence on the in-place quality of shotcreted concrete than craftsmen who form-and-pour concrete. In 2000, ASA and ACI 506 committee members worked with ACI Certification to develop a Shotcrete Nozzleman certification program to certify shotcrete nozzlemen. The engineers and specifiers recognized the benefit of having shotcreter certification and began specifying that only ACI-Certified Shotcreters place shotcrete on their jobs. Now most commercial shotcrete projects require current ACI Shotcreter certification. The ACI-Certified Shotcreter program currently has 2091 shotcreters worldwide. With specifiers having confidence in the credentials provided by the internationally recognized ACI certification program, use of shotcrete in concrete projects has increased substantially.



ACI CCS-4(20) – SHOTCRETE FOR THE CRAFTSMAN

This document provides the shotcreter an understanding of basic concrete technology, shotcrete equipment, surface preparation, shotcrete placement techniques, finishing, curing and protection of shotcreted concrete. It also covers the impact of weather conditions on shotcrete placement, safety and testing. This material is also duplicated in ACI CP-60 (see next).

ACI CP-60 – CRAFTSMAN WORKBOOK FOR ACI CERTIFICATION OF SHOTCRETE NOZZLEMEN

This workbook contains all the shotcrete information from ACI CCS-4 as that is covered in the certification written exam. It also includes sample questions at the end of each chapter for the shotcreter to review, a sample of the performance exam and the certification panel layout and evaluation. The format is spiral bound in a larger 8.5 x 11 in. (215 x 275 mm) format conducive to letting the shotcreter take notes in the book during education classes. The ACI Shotcreter certification written exam verifies that the shotcreter candidates have the basic shotcrete knowledge contained in the CP-60.

ACI CP-61PACK - SHOTCRETE INSPECTOR REFERENCE PACKAGE

This package of documents included in a notebook-style binder includes program information for the ACI Shotcrete Inspector Certification program, a sample exam, and reprints of ACI and ASA technical resource materials covered by the program. The collection is intended for those candidates taking the Shotcrete Inspector open book written exam, however it is a very cost-effective way to purchase these ACI and ASA documents and keep together as a ready reference on shotcrete in the office or field:

- ACI 305R-10, Guide to Hot Weather Concreting
- ACI 305.1-14, Specification for Hot Weather Concreting
- ACI 306R-16, Guide to Cold Weather Concreting
- ACI 306.1-90(02), Standard Specification for Cold Weather Concreting
- ACI 506R-16, Guide to Shotcrete
- ACI 506.1R-08, Guide to Fiber-Reinforced Shotcrete
- ACI 506.2-13, Specification for Shotcrete
- ACI 506.4R-94(04), Guide for the Evaluation of Shotcrete
- ACI 506.6T-17, Visual Shotcrete Core Quality Evaluation
- ACI CCS-4(08), Shotcrete for the Craftsman
- ASA, Safety Guidelines for Shotcrete

WRAPPING UP

A note of caution for contractors. While ACI provides excellent documents about concrete and shotcrete, the contractor is legally required by contract to comply with the specific project specifications and build the structure to meet the project specifications even though the project specification may conflict with provisions in the referenced ACI documents. The Shotcrete Guide has been erroneously referenced in contract documents with wording such as "Shotcrete work shall be as documented in ACI PRC 506-22 Shotcrete Guide". This has led to legal disputes since the Shotcrete Guide does not use mandatory language and thus is not strictly enforceable from a legal perspective. Specifiers are encouraged to use the mandatory ACI 506.2 in their contract documents or include modified language from the Shotcrete Guide to make the project requirements mandatory.

Though shotcrete has been around for over 100 years many architects and engineers are not familiar with the variety of shotcrete documents produced by ACI over the last 74 years. My advice to contractors is to get copies and become familiar with the above documents. If the project specification conflicts with ACI documents the contractor who is familiar with ACI documents can potentially head off a conflict by discussing the potential conflict with the specifier.

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

ACI-ASCC Survey on Portland-Limestone Cement Concrete

Summary of responses and comments

by James Klinger, Kevin A. MacDonald, Jerry A. Holland, Scott M. Tarr, Beverly A. Garnant, and Bruce A. Suprenant

This article originally appeared in the February 2024 issue of Concrete International. Reprinted courtesy of American Concrete Institute. Copyright 2024 ACI.

The transition from Type I portland cement (also referred to as ordinary portland cement [OPC]) to Type IL portland cement (also known as portland-limestone cement [PLC]) is well underway. The change has prompted many discussions among industry professionals in the United States. Unsurprisingly, the topic has been raised in many committee meetings at ACI Concrete Conventions.

At the Spring 2022 convention in San Francisco, CA, USA, Kevin MacDonald, Chair of ACI Committee 302, Construction of Concrete Floors, proposed a survey to gather information on contractors' experiences with PLC concrete. Beverly Garnant, Executive Director of the American Society of Concrete Contractors (ASCC) at the time, volunteered ASCC's assistance in the development and evaluation of the survey; and we, the co-authors of this article, served on the ensuing Joint ACI-ASCC Task Group that developed the survey questions. We also worked with Dean Frank, Executive Director of NEU: An ACI Center of Excellence for Carbon Neutral Concrete, and Michael Tholen, ACI Senior Managing Director of Technical Operations, to refine the questions.

This article presents 15 survey questions and a summary of answers provided by 173 respondents, as well as information from previous PLC surveys conducted by ASCC in March 2023,[1] the Tennessee Concrete Association (TCA) in June 2023,[2] and the National Ready Mixed Concrete Association (NRMCA) in October 2023.[3] Readers are encouraged to evaluate the ACI-ASCC PLC survey data and draw their own conclusions.

SURVEY BASICS

The Joint ACI-ASCC Task Group developed survey questions to gather information regarding the construction of concrete floors and slabs using Type I and Type IL portland cement. The following paragraphs discuss survey distribution, sampling methods, and responses.

DISTRIBUTION

ASCC's staff generated the survey in SurveyMonkey® and provided ACI staff with a URL link. The survey was distributed as an embedded link in the following media:

- Once per week in the Concrete SmartBrief—August 22 through September 30;
- In each ACI eNews—August 24 and September 7; and
- On ACI's LinkedIn and Facebook social media pages—August 16.

In addition, we (the authors) sent emails to our contacts at the Portland Cement Association (PCA), NRMCA, the California Nevada Cement Association (CNCA), and other groups to raise awareness of the survey and to encourage responses. The survey ended on September 30, 2023, with data collected from 173 respondents. While this may appear to be a small response, ACI staff has indicated that the largest previous survey, on the ACI Code 318 reorganization, included data from only 74 respondents.

SAMPLING

This survey featured nonprobability sampling based on links in emails to ACI members and contacts as well as postings on ACI's social media pages. Respondents had to take it upon themselves to submit responses, so the survey used a combination of convenience sampling and voluntary sampling. In contrast to the results of probability sampling based on random selection from a population, the results of this sampling approach are not suitable for statistical inference, and the results cannot be considered representative of all PLC users in the concrete industry.

RESPONSES

The survey comprised multiple-choice questions, with each accompanied by a text box for comments. Table 1 summarizes the quantities of responses and comments for each question. Because respondents could select multiple choices for many of the questions, the response rates exceed 100% for all but Questions 3 and 6. Respondents provided 288 comments. Although it is not practical to quote all comments in this article, a complete set is provided at **https://www.dropbox.com/scl/fo/4hox7s5jzvcud7rhied1e/h?rlkey=ml14in77igix8jn82qtight2e&dl=0.**

THE SURVEY SAYS…(QUESTIONS WERE EDITED FOR BREVITY)

Question 1: Select the profession that best describes your role in the concrete industry.

More than 80% of the respondents defined themselves as ready mixed concrete producers, concrete contractors, or architects/engineers. The remaining 20% of the respondents defined themselves as owners, testing agencies, construction manager/general contractors (CM/GC), or admixture and cement suppliers (Fig. 1).

Question 2: In what geographic region(s) does your company do business? (select all that apply)

Although it is not sufficient to establish causal relationships, this question provides an opportunity to determine if regional factors (for example, concrete constituents, climates, and construction practices) could be affecting project outcomes. Fig. 2 shows the states that comprise each region, while Fig. 3 shows the responses by region.

Question 3: Do you have experience with the use of Type IL cement concrete for floor/slab construction?

Because the subsequent questions concern the use of Type IL cement in the construction of concrete floors, the response to this question verifies appropriate industry experience. Ninety-four percent of the respondents indicated that they have been involved in floor construction projects that included Type IL cement.

Question 4: If you have not used Type IL cement concrete, do you expect to use it in the next 6 months?

As shown in Table 1, 91 respondents skipped this question, and 82 responded. Ten respondents (about 12%) indicated that they do not anticipate using Type IL cement in the next 6 months.

Question 5: With what types of floors/slabs do you have experience using Type IL cement concrete? (select all that apply)

The response to this question further establishes the legitimacy of the respondent's experience with floors. The 161 respondents provided 567 responses, an average of

Table 1:
Response quantities for survey questions 1 through 15

Question	Answered	Skipped	Responses	Comments
1	173	0	202	NA
2	173	0	314	NA
3	173	0	173	NA
4	82	91	82	NA
5	161	12	567	14
6	153	20	153	29
7	145	28	145	NA
8	138	35	500	38
9	136	37	193	16
10	154	19	374	25
11	137	36	354	21
12	135	38	265	NA
13	88	85	174	49
14	142	31	189	34
15	62	111	62	62
Total	2052	543	3747	288

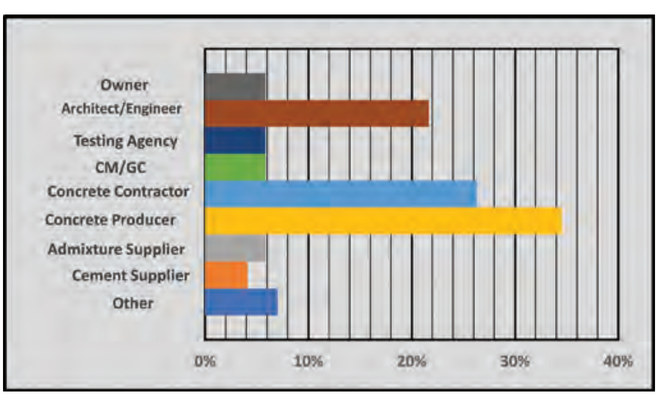


Fig. 1: Survey respondents by profession

Fig. 2: U.S. states representing each geographic region

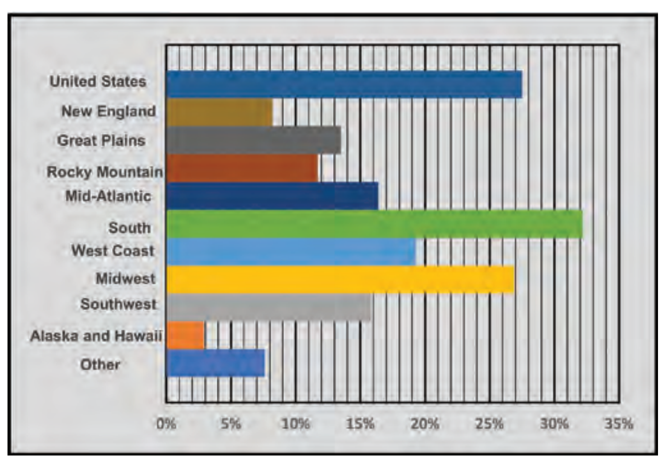


Fig. 3: Geographic regions in which respondents' companies operate

about 3.5 floor types per respondent. As shown in Fig. 4, over 90% of the respondents were familiar with interior slabs with a trowel finish, and over 80% were familiar with exterior slabs with a broom finish. Fewer respondents had experience with lightweight concrete (42%), topping slabs (44%), decorative (38%), or polished (45%) slabs. This was the first question that allowed for comments, and 14 comments were provided.

Question 6: If you used Type IL cement concrete, did you experience any problems? If so, did they occur at a greater, the same, or at a lower frequency than with Type I cement concrete? (choose one answer)

More than half the respondents indicated they had experienced problems more frequently with Type IL cement concrete than with Type I cement concrete (56%). Most of the remaining respondents reported that problems were occurring at the same frequency (43%), and a few respondents indicated that problems were occurring at a lower frequency with Type IL cement concrete than with Type I cement concrete (1%).

Table 2 shows responses to Question 6, categorized by the profession (industry role) of the respondent. Most of the responding cement producers (86%) and ready mixed concrete producers (60%) believe that problems experienced during the construction of concrete slabs and floors

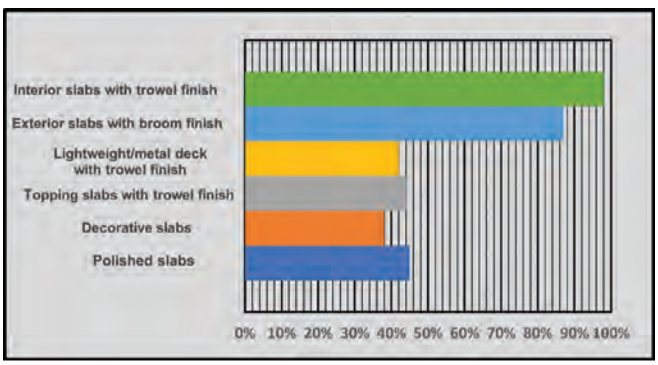


Fig. 4: Floor/slab types in which survey respondents used PLC concrete

Table 2:
Perception of occurrence of issues associated with change in cement type, tabulated by profession (role)

Profession	The same frequency, %	Lower frequency, %	Greater frequency, %
Owner	20	0	80
Architect/engineer	47	0	53
Testing agency	40	0	60
CM/GC	40	0	60
Concrete contractor	26	2	72
Concrete producer	60	2	38
Admixture supplier	11	0	89
Cement producer	86	0	14
Other	30	0	70

are occurring at the same frequency, regardless of the cement type. Admixture suppliers (89%), owners (80%), and concrete contractors (72%), however, believe problems are occurring at a greater frequency in floors constructed using Type IL portland cement. Clearly, perception is a function of perspective.

Comment summary: Of the 29 comments associated with Question 6, seven mentioned strength issues. Other problems mentioned were cracking; setting times, both retarded and accelerated; water demand; slump variation; scaling; and finishing. Special circumstances were also mentioned, including cold weather placements and use of high-performance concrete mixtures. Seven respondents commented that they had had no problems. One comment stated the belief that using Type IL on troweled slabs is a serious problem which requires study.

Question 7: Is there a cost difference between using portland-limestone cement (PLC) (ASTM C595/C595M4) concrete versus ordinary portland cement (OPC) (ASTM C150/C150M5) concrete?

Many surveys ask at least one question that is not understood or, in retrospect, not important. Question 7 is our albatross. We provided a slider bar so respondents could indicate cost differences ranging from -25% to +25%. But we also provided a text box—some respondents input cost difference as a percentage and others as a dollar value. Although 145 respondents provided answers, we could not calculate percentages based on dollar inputs. We also recognized after the fact that the cost difference isn't relevant.

Question 8: Compared to OPC concrete, did you experience any of the following when using PLC concrete, an increase or decrease in: (a) water demand, (b) set times, (c) bleed water, (d) crusting, (e) air content, (f) finishing, (g) pumping, (h) evaporation reducers, and (i) dry shakes? (select all that apply)

Fig. 5 illustrates the choices as an increase or decrease in characteristics stated in the question. The top responses, with over 30% reported change, include water demand, set times, crusting, finishing, evaporation reducers, and bleeding.

Comment summary: The respondents provided 38 comments. Strength problems, cracking, water demand, and a need for more admixtures were the most commonly cited issues. Shrinkage, variation in slump, inconsistent setting, a short finishing window, scaling, saw-cutting issues, color matching difficulties, and problems arising with mixtures with SCMs were also mentioned. Nine of the 31 commenters experienced no differences.

Question 9: Compared to OPC concrete, did you experience any of the following when using PLC concrete: similar amount of cracking or an increase or decrease in drying shrinkage cracking and plastic shrinkage cracking? (select all that apply)

While cracking can be a structural, durability, serviceability, or aesthetic issue (or of no concern), it invariably starts a jobsite discussion and thus is a good topic for a question. Fig. 6 illustrates the responses to choices listed in the question. The 136 respondents provided 193 responses. While many respondents reported that they experienced the same amount of cracking regardless of the cement type, others experienced an increase in drying and plastic shrinkage cracking associated with PLC placements.

Comment summary: The 16 comments on this question varied with issues including location/weather, shrinkage cracking, use of SCMs, volume change behavior, full-depth slab cracking, and delamination. Four of the comments indicated no problems. One respondent solved the encountered problems with wet curing and wind barriers. Another believes that, "proper finishing practices eliminate the issues."

Question 10: Compared to OPC concrete, did you experience any of the following when using PLC concrete: (a) no strength problems or an increase or decrease in strength at (b) 28 days, (c) 7 days, (d) 3 days, (e) after 28 days, or low strength that affected (f) construction, (g) form removal, or (h) post-tensioning stressing? (select all that apply)

As with cracking, low strength also generates jobsite discussions. Fig. 7 illustrates the responses to choices listed in the question. Over 30% of the respondents reported they had experienced no strength problems. However, the same percentage of respondents reported that they had experienced strength problems at 28-, 7-, and 3-days.

Comment summary: Respondents provided 25 comments. While comments for this question were diverse, strength issues were cited as the number one problem. However, one respondent reported that strength problems were solved by using slag cement in mixtures. Six participants reported no problems with the queried topics. Others noted that improper curing or SCMs caused difficulties. Specific comments included:

- "…so many factors, it is hard to pin it all on PLC."
- "…material needs to be designed to meet performance criteria,"
- "…lab tests show similar performance on mix design work."

Question 11: Compared to OPC concrete, did you experience any of the following during ready mixed production when using PLC concrete: (a) no significant changes; or an increase or decrease in: (b) number of trial batches, (c) cementitious content, (d) admixture dosage, (e) admixture types, (f) fly ash content, (g) slag content, and (h) water demand? (select all that apply)

Specific to ready mixed concrete production, Fig. 8 illustrates responses to the choices included in the question. More than 20% of the respondents reported no significant changes. However, even greater percentages of respondents indicated that PLC mixtures led to increases in the number of trial batches, cement content, admixture dosage, and water demand. Both Questions 8 and 10 asked about water demand and received about the same response—an indication of consistency in the survey results.

Comment summary: Of the 21 comments provided for this question, those regarding admixtures ranged from "highly variable" to "very slight." Four comments indicated that the respondents had found no differences between OPC and PLC. Interesting remarks included:

- "We never accepted the industry message that it was the same."
- "The majority of producers have not done their due diligence, and have elected to do a 1:1 swap based on information from their cement salespersons."
- "This is a way more serious situation than the industry is making it out to be."

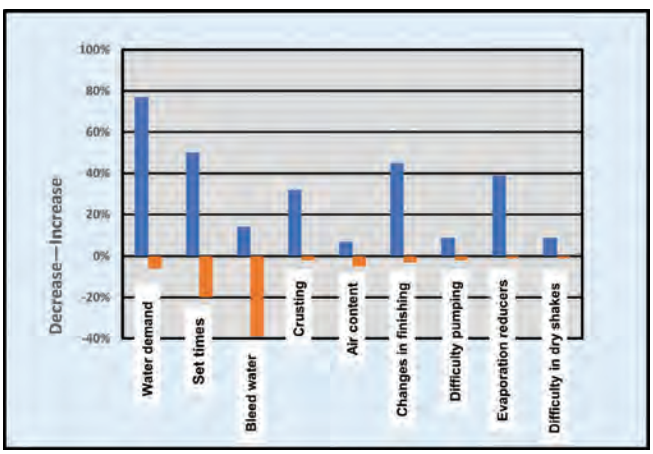


Fig. 5: Changes in characteristics observed by survey respondents when using PLC concrete versus OPC concrete. Positive (blue) bars indicate increased incidences, and negative (orange) bars indicate decreased incidences

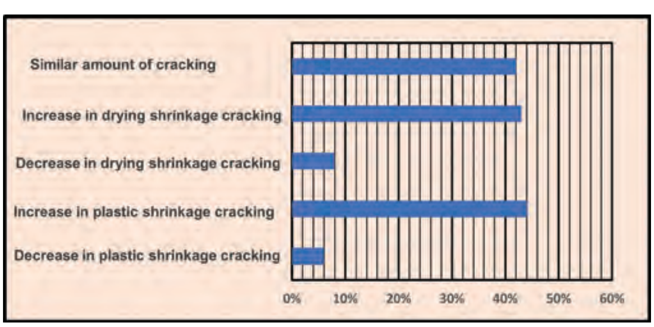


Fig. 6: Changes in cracking observed by survey respondents when using PLC concrete versus OPC concrete

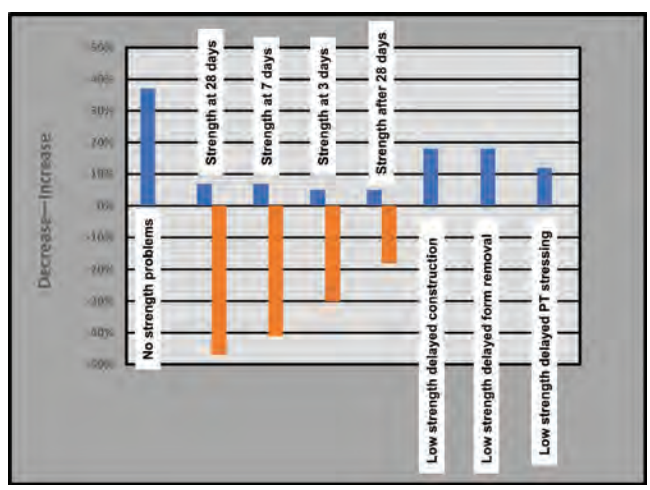


Fig. 7: Changes in strength development when using PLC concrete versus OPC concrete observed by survey respondents. Positive (blue) bars indicate increased strength, and negative (orange) bars indicate decreased strength

Question 12: Compared to OPC concrete, did you experience any of the following when using PLC concrete: (a) no significant changes; or an increase or decrease in: (b) random cracking, (c) wear resistance, (d) dusting, (e) scaling, (f) discoloration, (g) curling, and (h) delamination? (select all that apply)

The choices were based on Chapter 13 of ACI 302.1R-15.[6] Fig. 9 illustrates responses to the question. The top response (at 50% of respondents)—no significant changes experienced. The second-place response (at about 35% of respondents)—increase in random cracking. The third-place result (at 20% of respondents)—decrease in wear resistance. Both Questions 9 and 12 asked about random cracking, receiving about the same response, again indicating consistency in the survey results.

Question 13: Compared to OPC concrete, did you experience any of the following when using PLC concrete: changes in (a) timing of saw cutting, (b) curing, (c) cold weather placement, and (d) hot weather placement? (select all that apply)

Fig. 10 provides the percentages of respondents who indicated that changes were experienced in the indicated construction activity. Interestingly, 70% of the respondents reported changes in timing of saw cutting, and over 38% respondents reported changes in each of the other queried practices. While the question wasn't specific to the changes, respondents provided comments that were specific.

Comment summary: Forty-nine people commented on this question, with 17 saying they'd experienced slight to no differences. As for the other comments, the primary complaint (11 comments) was with the timing of joint saw cutting:

- "Water demand issues have resulted in us having to adjust our timing of saw cuts and amount of curl."
- "Intermittent setting and unpredictable set times…made timing the saw cuts difficult."

Other problems mentioned included increased water demand, shrinkage cracking, cylinder difficulties, finisher overtime, strength issues, and delamination.

Question 14: Compared to OPC concrete, did you experience any problems when using PLC concrete? If so, to whom do you most attribute the problems? (select one answer)

This was a perception question, as it asked owners, designers, contractors, ready mixed concrete producers, and cement suppliers to place blame for perceived problems. About 25% indicated that they had had no problems, while the majority (above 50%) expressed a belief that cement suppliers are the root of the issues. Table 3 provides the responses, listed by profession. Obviously, opinions vary with the respondents' roles.

Comment summary: There were 34 comments. Cement manufacturers and ready mixed concrete producers took the hardest hit with comments such as:

- "A lack of transparency on cement content/fly ash replacement."
- "The clinker is not getting ground enough, and the resulting cement performance is diminished."

Engineers/designers also received criticism such as:

- "It's a material issue; some Engineers have no experience with it and hold true to specifications that work for Type I/II but not with IL."

Also blamed were contractors, labs, the government, the industry at large, owners, and general contractors.

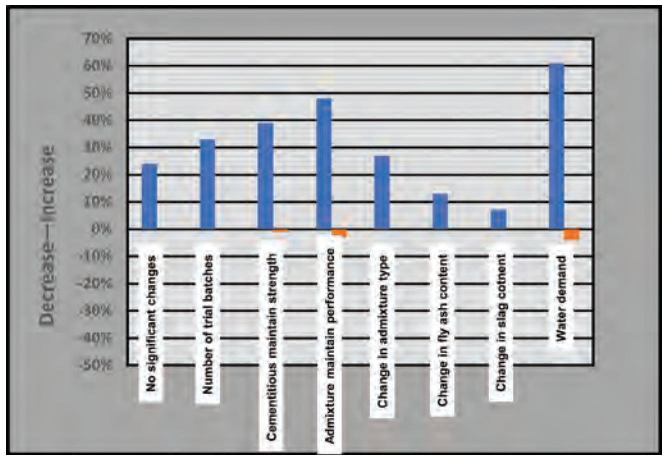


Fig. 8: Changes during ready mixed PLC concrete production versus OPC concrete production observed by survey respondents

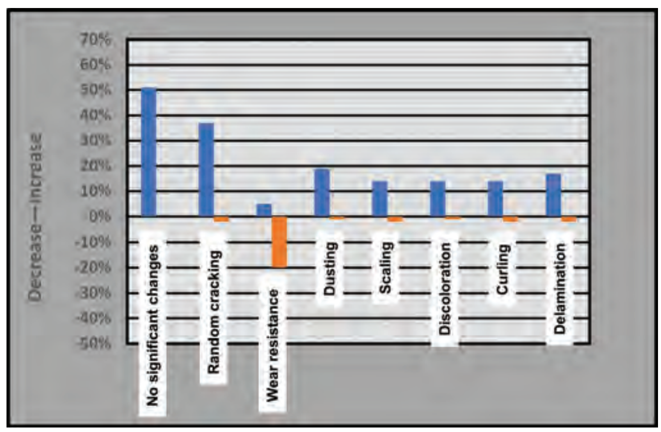


Fig. 9: Changes observed by survey respondents when using PLC concrete versus OPC concrete. Choices were based on Chapter 13 of ACI 302.1R-156

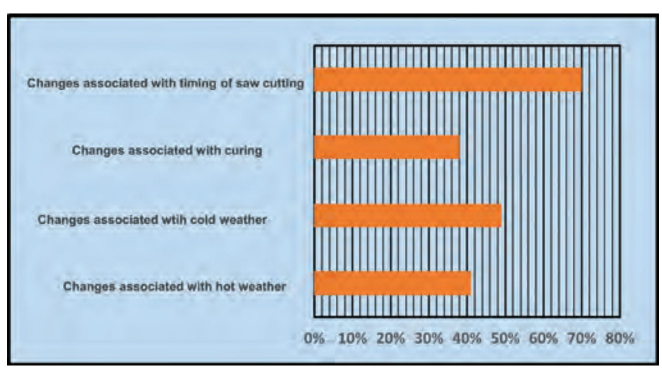


Fig. 10: Changes in specific construction activities when using PLC concrete versus OPC concrete observed by survey respondents

Question 15: Provide additional comments on floor and slab construction as appropriate for ACI Committee 302?

Comment summary: In response to this question, 13 of the 62 respondents indicated they had experienced few or no problems using PLC cement. The remainder included very specific concerns, solutions, or calls for honest communication:

- "There seems to be an increase in the frequency of reduced hydration at the surface."
- "We have recommended test slabs on all projects, which has successfully avoided issues."
- "Producing good IL takes good companies, people, and goals. We just need to start over creating mixes and not assume the material is the same as OPC regardless of what industry touted to get it going."
- "The issues with IL are evident everywhere and have to be highlighted. Problems in the field result in multiple lawsuits which is not what the industry wants."

ASCC, TCA, AND NRMCA PLC SURVEYS

ASCC—The ASCC PLC survey, titled "ASCC Survey on Contractor Experience with Type IL Cement," consisted of 17 questions asking members to report their experiences with Type IL cement (PLC). The survey was sent out in December 2022. A total of 36 responses were received, and they were summarized in the March 2023, ASCC Newsletter.[1] The responses are presented in Tables 4 and 5 in this article. The respondents are structural concrete contractors located throughout the United States. Although company size varied, 22 contractors reported annual sales volume of more than 50 million USD. The survey focused on three main potential PLC problem areas: compressive strength, fresh concrete setting times, and water demand.

Respondents were also given the opportunity to describe other issues, including potential problems with finishability, shrinkage cracking, and effects of cold weather. No respondents indicated PLC issues related to decorative or polished concrete. It should be noted that some respondents declined to answer all questions.

TCA—The survey was sent out to TCA members from April to June 2023. The survey received 23 responses from 15 ready mixed concrete producers and eight concrete contractors. Nineteen responded that they had problems or changes when using Type IL cement. Twenty-one selected all that apply (refer to Fig. 11).

NRMCA—During the summer of 2023, a phone survey was conducted to assess NRMCA producers' experiences with PLC. The survey was summarized in October 2023 and presented at NRMCA's ConcreteWorks (refer to Tables 6 and 7). Twenty-two companies were surveyed; six were vertically integrated producers, nine were large independent

Table 3:
Problems with PLC concrete versus OPC concrete, attributed to specific professions by respondents' profession

Respondents' profession	We have had no problems, %	Owners, %	Designers, %	Contractors, %	Concrete producers, %	Cement suppliers, %
Owner	11	0	22	11	11	67
Architect/engineer	23	8	8	12	42	62
Testing agency	38	0	0	13	38	38
CM/GC	45	20	0	0	20	35
Concrete contractor	22	6	19	6	19	64
Concrete producer	33	6	17	21	2	42
Admixture supplier	0	0	14	29	14	86
Cement supplier	71	0	0	0	14	14
Other	0	11	22	0	55	89

Table 4:
ASCC Survey—Type I and IL cement use

Question	Yes	No	Type I only	Type IL only	Type I and IL	1:1 replacement	Other
Concrete contains Type IL cement	33	3	—	—	—	—	—
Cement types available	—	—	3	11	14	—	—
Content replacement of Type IL for Type I	—	—	—	—	—	18	1, 2, 3, 4, 5 (see footnotes)

1. Started at 1:1 but adding more Type IL as the strengths are about 5% lower
2. Depends on suppliers, some using 1:1 replacement, others adding an extra 20 to 30 lb (9 to 14 kg) of cement to maintain strengths
3. Replacing 1:1 Type IL for Type I
4. Increase Type IL by 100 lb (45.4 kg) over Type I to achieve same 4000 psi (27.6 MPa) strength at 28 days
5. Add about an extra half sack of cement for Type IL as compared to Type II/V to obtain same 28-day strengths

producers, and seven were small independent producers. The survey included nine, eight, and five producers in the Eastern (nine), Central (eight), and Western (five) geographic regions of the United States.

SURVEY COMPARISON

Table 8 provides the responses to eight questions that were common to the ACI-ASCC, ASCC, TCA, and NRMCA surveys. The responses are in reasonable agreement across the surveys, further confirming the consistency of the ACI-ASCC survey results.

COOPERATION AND COLLABORATION

In December 2022, the CEO of the Portland Cement Association (PCA) encouraged cooperation and collaboration in efforts to produce sustainable concrete, stating that "working together is the vehicle to our success."[7] In December 2023, he further indicated that achieving carbon neutrality requires global collaboration among public and private sectors.[8] We certainly agree with these sentiments, and we believe that most survey respondents would also agree that cooperation and collaboration is an essential condition

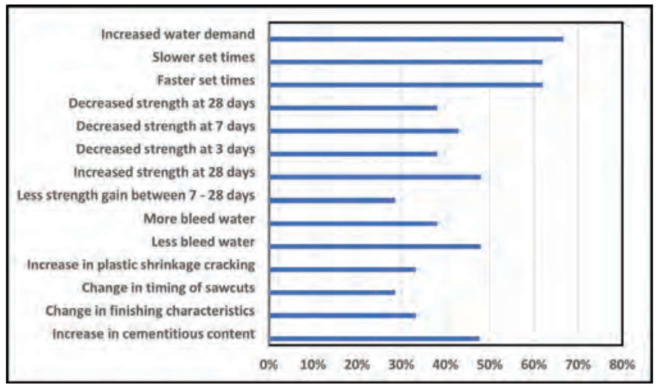


Fig. 11: TCA member responses on experiences with PLC concrete versus OPC concrete from 21 participants

Table 5:
ASCC Survey—strength, set time, water demand, and other issues

<table>
<tr><th>Question</th><th>Yes</th><th>No</th><th colspan="2">Amount lower</th></tr>
<tr><td>Have you had any strength issues with Type IL cement?</td><td>14</td><td>13</td><td colspan="2">1. 5 to 10% lower; made strength at 56 days
2. About 10% lower
3. Up to 500 psi lower
4. Roughly 10 to 15% lower
5. Up to 25% lower
6. Up to 500 psi lower
7. 500 to 1000 psi lower
8. 10 to 15% lower
9. Increased cement content by half sack
10. About 200 to 400 psi at 28 days
11. Low 3-day by 10 to 15%
12. Low 3-day by 7%
13. Low 7-day by 10%</td></tr>
<tr><td rowspan="2">Have you had any fresh concrete set issues?</td><td rowspan="2">14</td><td rowspan="2">14</td><td>Retarded</td><td>Accelerated</td></tr>
<tr><td>1. 1 to 2 hours
2. Longer, made worse by cold weather
3. Longer by 45 to 60 minutes
4. Up to 2 hours
5. 30 minutes
6. Longer by 20 to 30%
7. Longer by 60 to 90 minutes</td><td>1. 10 to 15% faster
2. Faster by 25%
3. Faster
4. Faster by 30 to 60 minutes when pumping</td></tr>
<tr><td rowspan="2">Have you had any issues with increased water demand?</td><td rowspan="2">10</td><td rowspan="2">14</td><td colspan="2">Comments</td></tr>
<tr><td colspan="2">1. Much higher water demand; shrinkage cracking and workability issues
2. Drinks up water, makes it hard to flow. Spend more time working it, and less time finishing it. Creates more man hours per job
3. About 2 to 10% increase in water
4. Requires more water, makes strength less
5. More shrinkage cracking due to water demand
6. Batch plant confirms more water or water reducer used</td></tr>
<tr><td colspan="3" rowspan="2">Other issues with Type IL cement?</td><td colspan="2">Comments</td></tr>
<tr><td colspan="2">1. Abrasion (2)
2. Finishability (11)
3. Workability (4)
4. Proper curing (4)
5. Cold weather work (10)
6. Shrinkage (6)
7. Pumpability (1)
8. Availability (2)
9. Cost premiums (4)</td></tr>
</table>

Note: 100 psi = 0.7 MPa

Table 6:
NRMCA Survey—PLC information

Question	Responses
Number of sources of cement	1. Sources varied from one to eight plus; some with more than one source at single plants; some imports 2. Several provided copies of mill test reports of OPC and PLC from same source
Availability of ASTM C150/C150M portland cement	1. 60% have only PLC 2. Some have sources that haven't switched; some have Type V availability; some imports
Information tracked or evaluated on PLC	1. Mill test reports are generally reviewed but not always useful for QC; reporting for ASTM C595/C595M is not too useful 2. Info reviewed included limestone (LS) content; Blaine fineness; SO3; alkali content; grinding aids; cube strength 3. 70% of PLC sources have LS content between 8 to 10%; others are at 10 to 15%; some sources indicate it will increase with time 4. Some concern of observed impact when LS > 10% 5. Blaine varies from 400 to 500+; change in Blaine not always consistent with LS content
ASTM C917/C917M for PLC (uniformity of single source based on strength)	1. 50% obtain and review; some sources don't have ASTM C917/C917M available 2. Generally, don't observe significant change in variability for individual sources
Evaluations performed with PLC	1. All performed trial batches; some compared OPC with PLC; some established 3-point curves; many evaluated production batches; most included SCMs and admixtures in additional trial batches 2. Some perform mortar tests; monthly concrete trial batches; calorimetry, some did more comprehensive evaluations—water demand, setting time, bleeding, admixture dosage and combinations; external testing included particle size distribution, composition, LS content, etc. 3. Some did durability testing—ASR, permeability—generally no issues
PLC content in mixtures	1. 70% indicated they used 1:1 replacement (generally with LS < 10%) 2. Some increased PLC 3 to 8% for 28-day strength; some have since reduced this; some SCMs work better with PLC for strength
SCM type and content	1. SCM used included Class C & F fly ash; slag cement; natural pozzolan 2. Generally, no changes to SCM content; some reduced for flatwork; some observed better SCM performance; some did not

Table 7:
NRMCA Survey—Impact of PLC on concrete

Question	Responses
Strength and strength gain	1. 50% noted lower 28-day strength; some see greater strength reduction with air-entrained mixtures
	2. 30% noted lower early-age strength
	3. Some observed strength flattens out after 7-days; some see later age strength gain
Water demand	1. Most observed increased water demand; 60% observed increases between 1 to 2 g/yd^3; adjusted with admixtures
Admixture dosage	1. 40% increase in water reducer (WR) dosage; most increase in air-entraining admixture dosage—some observed unstable air
	2. Source specific issues—WR not effective; admixture combinations WR and high-range WR or medium range WR combinations had to be changed
Setting time	1. 30% slightly retarded; 10% slightly accelerated; 60% no change or did not check
Changes to mixtures with PLC	1. 50% indicated no change; 20% increased cement 3 to 8%; some could live with reduced over-design
	2. Adjustments on admixture combinations and dosage
Observed variability of PLC	1. 90% did not observe increased variability for individual sources; some indicated variability with changes in LS and fineness—observed general improvement from earlier supply when LS content was not changing
	2. Considerable variability between sources—issues with filling silos with varying source shipments

Table 7: Continued

Evaluations with shipments	1. Most do not check or evaluate shipments
	2. 10% collect samples for mortar tests; most check changes in concrete mixtures
	3. Mill test reports not very useful for this purpose
Restrictions and required approvals/submittals	1. Some with Department of Transportation (DOT) initially; generally, not a problem if DOT approved PLC; most required some typical mixture data; some required production evaluation
	2. Many companies performed trial batches on most of their typical mixtures in preparation for required submittals
	3. Some issues with other designers (private construction) generally resolved with letters or new submittals; many due to lack of awareness or specification not referencing ASTM C595/C595M
	4. Restrictions on some U.S. Army Corps of Engineers and Federal Aviation Administration projects; environmental structures; hospitals; sulfate resistance requirements preference for Type V; lack of compliance with sulfate resistance for PLC, interior slabs
Perceptions of customers (contractors)	1. 10% indicated higher shrinkage; 10% indicated improved finishability; most indicate less bleed
	2. Concerns mentioned (not much basis for claims)—change in finishability for slabs; crusting; change in setting time; increased plastic shrinkage cracking; premature sealing; adjustments needed for early age strength (PT, tilt up, formwork)

Note: 1 g/yd^3 = 1.3 g/m^3

for the industry to move forward with sustainable concrete construction.

Although the Joint ACI-ASCC survey was based on a small sample size, we were discouraged to find that 80% of the owners say that concrete problems are occurring at a greater frequency with PLC than with OPC. We find hope, however, in a survey response calling for a summit meeting between PCA, NRMCA, and ASCC, adding:

- "This situation is very serious and needs to be addressed immediately."

We wholeheartedly agree and hope that a cement and concrete industry summit takes place no later than Summer 2024. We recommend that the ACI NEU Center of Excellence serve as the facilitator for continuing communication, cooperation, and collaboration.

Table 8:
Comparison of survey responses

Issue	ACI-ASCC Fall 2023	NRMCA Summer 2023	TCA June 2023	ASCC December 2022
1. Strength, %	45	50	35	50
2. Water demand, %	75/60*	60	65	60
3. Set time, %	45	40	60	50
4. Bleed water, %	40	NA†	50	NA†
5. Plastic shrinkage cracking, %	45	X‡	35	30
6. Saw cut, %	70	NA†	30	NA†
7. Finishing, %	45	X‡	35	35
8. Cement content, %	35	20	50	NA†

**Question asked twice receiving a 75% and 60% response*
†Represents survey did not ask question on this topic
‡Represents an issue but no percent reported

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Selected for reader interest by the editors.

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ACI Honorary Member **Beverly A. Garnant** *is a former Executive Director of ASCC and Co-Chair of ASCC Sustainability Committee. She is a member of ACI Committees 134, Concrete Constructability; C641, Decorative Concrete Finisher Certification; and E703, Concrete Construction Practices.*

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Why Membership Benefits Refractory Contractors

By Ted Sofis

In March 2024, at the ASA committee meetings in Austin, TX, the question came up about refractory contractors, and why that industry segment is so under-represented in the association. Considering my background, I felt qualified to address the issue. Much of my work involved shotcrete installation of refractory material. I began gunning refractory and lining steel teeming ladles in 1975, at the J&L Aliquippa Works. I gunned blast furnace troughs at United States Steel, Wheeling Pittsburgh Steel, and Crucible Specialty Steel. Over subsequent years, we've serviced the power industry, installing gunned refractory in power plant ash hoppers, burners, baffles, and power plant penthouse areas in Pennsylvania, Ohio, West Virginia, New York and Maryland.

Fig. 1: Shotcreter placing refractory

Fig. 2: Shotcreter in the foreground

REFRACTORY SHOTCRETE

Since the invention of shotcrete by Carl Akeley, refractory contractors have been at the forefront of utilizing the process for a variety of industrial applications. Early on, gunning of shotcrete began to replace brick because of the cost benefits and ease of application. Shotcreted monolithic linings could take any shape. Dry-mix shotcrete provided an efficient method for lining steel ladles, blast furnaces, and blast furnace troughs in the steel industry. In the power Industry, refractory could be installed in ash hoppers without requiring formwork. Because wet-mix shotcrete generally used ready-mix concrete, the method was not normally used for refractory shotcrete. At the time, pre-packaged refractory materials could not be mixed quickly enough to keep up with a shotcrete pump.

With the advent of the high-capacity pan mixer, this changed in the 1990s. Today, pan mixers that can handle 2200 lbs (1000 kg) pre-packaged bags of refractory are commonly used with wet-mix shotcrete installations. Both dry-mix and wet-mix have refractory mixtures that are designed specifically for each method. Some of the refractory dry-mix mixtures are among the best shotcreting pre-packaged materials on the market. Great progress has been made over the years in research and development. Beginning with castable mixtures, calcinated fireclay was added to make the shotcreted material sticky enough to hold it in

SHOTCRETE CORNER

Por qué la membresía beneficiaría a los contratistas refractarios

Por Ted Sofis (Raúl Bracamontes, Editor de Traducción)

En marzo de 2024, durante las reuniones del comité ASA en Austin, TX, surgió la pregunta sobre los contratistas refractarios y por qué ese segmento de la industria está tan subrepresentado en la asociación. Dada mi experiencia, me sentí capacitado para abordar el problema. Gran parte de mi trabajo involucró la instalación de concreto lanzado de material refractario. Comencé a colocar concreto lanzado vía seca refractario y revestir cucharas de colada en acero en 1975, en J&L Aliquippa Works. Proyecté canales de altos hornos en United States Steel, Wheeling Pittsburgh Steel y Crucible Specialty Steel. En los años siguientes, hemos prestado servicio a la industria eléctrica, instalando concreto lanzado refractarios en tolvas de cenizas de plantas eléctricas, quemadores, deflectores y áreas de penthouse de plantas eléctricas en Pennsylvania, Ohio, West Virginia, New York y Maryland.

Fig. 1: Boquilla colocando refractario

Fig. 2: Boquilla en primer plano

CONCRETO LANZADO REFRACTARIO

Desde la invención del concreto lanzado por Carl Akeley, los contratistas refractarios han estado a la vanguardia en la utilización de este proceso para una variedad de aplicaciones industriales. Desde el principio, la proyección de concreto comenzó a reemplazar al ladrillo debido a los beneficios económicos y la facilidad de aplicación. Los revestimientos monolíticos de concreto podían adoptar cualquier forma. El concreto lanzado en seco proporcionaba un método eficiente para revestir las cucharas de acero, hornos de coque y canales de altos hornos en la industria del acero. En la industria energética, el material refractario podía instalarse en tolvas de ceniza sin necesidad de cimbra. Debido a que el concreto lanzado en húmedo generalmente utilizaba concreto premezclado, este método no se utilizaba normalmente para concreto lanzado refractario. En ese momento, los materiales refractarios preenvasados no podían mezclarse lo suficientemente rápido como para mantenerse al ritmo de una bomba de concreto lanzado.

Con la llegada de la mezcladora de paleta de alta capacidad, esto cambió en la década de 1990. Hoy en día, las mezcladoras de paleta que pueden manejar bolsas preenvasadas de material refractario de 2200 libras (1000 kg) son comúnmente utilizadas en instalaciones de concreto

Fig. 3: Pan Mixer Pump combo

Fig. 4: Bag slicer for 2,200 bulk bags of pre-packaged refractory

place until the cement began to set. Sharper aggregates were added and adjusted, to keep the shotcrete delivery hoses clean. The technology has progressed, and we now have ultra-low cement concrete designed specifically for shotcrete placement. There are also cement-free and insulating mixtures.

ASA MEMBERSHIP

One of the strengths of the American Shotcrete Association is it has brought contractors, manufacturers, and engineers all together. We talk about issues we have in the industry and share the problems that we encounter. The ASA provides resources to better train and educate our staff - from the owners to project managers to the field team. Some things are as simple as understanding why certain procedures are important. I found interacting and networking with others in the industry is one of the things that I enjoyed the most, and the most beneficial to me in my business. By working together on ASA committees, we are exposed to what is being done in other industry segments and learn about what is going on in other parts of the country. Regardless of what we think we know, there is always much more to learn.

The majority of refractory customers are privately-owned companies. I believe refractory contractors don't want others to know who they are working for. They are protective of their customers. I believe such fears are without merit. The interaction with others in the business and the synergy that can be developed far outweigh any such concerns. It's nice to pick up the phone and talk with someone encountering similar issues or problems. You build a personal network of shotcrete professionals, who can offer solutions or even a friendly suggestion when you need a helping hand.

EDUCATION AND SHOTCRETER CERTIFICATION

Customers and engineers want to see qualified bidders with a well-trained workforce. The American Shotcrete Association offers shotcrete education along with the ACI Shotcreter (previously known as Nozzleman) Certification. In the education portion of the certification process, all aspects necessary for proper shotcrete installation are covered and explained. This education includes both the dry- and wet-mix processes. It includes proper technique, good practices and safety considerations specific to shotcrete placement. It explains the chemical reactions that occur in concrete, proper curing, acceptable environmental conditions for installation. The "little things" matter in achieving quality placement. Understanding the reasons behind why we do things is important. The shotcreter certification involves both a written portion and a performance exam. In the performance exam, we grade the shotcreter's safety procedures, shooting technique and general performance in shotcreting a test panel. The certification candidates shoot a vertical panel and if qualified by experience, an additional overhead panel. The panels are then cored, and the cores graded for the encapsulation of the embedded reinforcing bars and undesirable voids. Refractory contractors shoot a much larger variety of materials than the average shotcrete contractor. These materials range from conventional dry-mix mixtures, to low-cement and light-weight insulating mixes. In all cases, there are embedded metals to shotcrete around, such as reinforcing bars, V-Type refractory anchors or conduits. An experienced dry-mix shotcreter needs to adjust the air and water as needed. The same principles apply whether you're shooting refractory or conventional

Fig. 3: Combinación de bomba mezcladora de bandeja

Fig. 4: Cortadora de bolsas para 2.200 bolsas a granel de refractario preenvasado

lanzado vía húmeda. Tanto el concreto lanzado en seco como el lanzado en húmedo tienen mezclas refractarias diseñadas específicamente para cada método. Algunas de las mezclas refractarias premezcladas están entre los mejores materiales preenvasados de concreto lanzado en el mercado. Se ha avanzado mucho a lo largo de los años en investigación y desarrollo. Comenzando con mezclas colocadas con cimbra, se agregó arcilla refractaria calcinada para hacer que el material proyectado fuera lo suficientemente pegajoso (cohesivo) como para mantenerlo en su lugar hasta que el cemento comenzara a fraguar. Se agregaron y ajustaron los agregados dosificando agregados más agudos para mantener limpias las mangueras de entrega de concreto lanzado. La tecnología ha progresado, y ahora tenemos mezclas de concreto lanzado ultra bajos en cemento diseñadas específicamente para su colocación. También existen mezclas sin cemento y aislantes.

MEMBRESÍA EN ASA

Una de las fortalezas de la Asociación Americana de Concreto Lanzado (ASA) es que ha reunido a contratistas, fabricantes e ingenieros. Hablamos sobre los problemas que tenemos en la industria y compartimos los problemas que encontramos. ASA proporciona recursos para capacitar y educar mejor a nuestro personal, desde los propietarios hasta los gerentes de proyecto y el equipo de campo. Algunas cosas son tan simples como entender por qué ciertos procedimientos son importantes. Descubrí que interactuar y establecer contactos con otros en la industria es una de las cosas que más disfruté, y la más beneficiosa para mí en mi negocio. Al trabajar juntos en los comités de ASA, estamos expuestos a lo que se está haciendo en otros segmentos de la industria y aprendemos sobre lo que está sucediendo en otras partes del país. Independientemente de lo que creamos saber, siempre hay mucho más por aprender.

La mayoría de los clientes refractarios son empresas privadas. Creo que los contratistas refractarios no quieren que otros sepan para quién están trabajando. Son protectores de sus clientes. Creo que tales temores carecen de fundamento. La interacción con otros en el negocio y la sinergia que se puede desarrollar superan con creces tales preocupaciones. Es agradable levantar el teléfono y hablar con alguien que enfrenta problemas o dificultades similares. Construyes una red personal de profesionales del concreto lanzado que pueden ofrecer soluciones o incluso una sugerencia amistosa cuando necesitas una mano amiga.

EDUCACIÓN Y CERTIFICACIÓN DE CONCRETEROS

Los clientes e ingenieros quieren ver contratistas calificados con una fuerza laboral bien capacitada. La Asociación Americana de Concreto Lanzado ofrece educación sobre concreto lanzado junto con la Certificación ACI de lanzadores de concreto. En la parte educativa del proceso de certificación, se cubren y explican todos los aspectos necesarios para una instalación adecuada de concreto lanzado. Esta educación incluye tanto los procesos de via seca y vía húmeda. Incluye técnicas adecuadas, buenas prácticas y consideraciones de seguridad específicas para la colocación de concreto lanzado. Explica las reacciones químicas que ocurren en el concreto, el curado adecuado, las condiciones ambientales aceptables para la instalación. Los "detalles" importan para lograr una colocación de calidad. Comprender las razones detrás de por qué hacemos las cosas es importante. La certificación de los lanzadores implica tanto un examen escrito como un examen práctico. En el examen concrete. The shotcreter needs to use the proper placement angles, keep the nozzle the proper distance from the receiving surface, and maintain high velocity for compaction and full encasement. Whether you're encapsulating reinforcing bar or V-type refractory anchors, the goal is the same. The candidates must pass both the written exam and the performance exam to receive ACI Shotcreter Certification. The ACI certification conducted by ASA is a credential that is widely recognized by engineers, private firms and public agencies.

TECHNICAL RESOURCES

ASA gathers a wealth of knowledge resources on all things related to shotcrete. ASA Conventions are just one venue where shotcrete-centered presentations come together. Recently at the Shotcrete Convention in Austin, TX, I sat in on a presentation where Marc Jolin's group at Laval University presented test results from various dry-mix nozzles and how effective or ineffective they were and which produced the best results. Shotcrete magazine is another valuable resource. Over the years I've written articles in Shotcrete magazine explaining why bonding compounds are not required or even recommended with shotcrete placement. Several contractors have approached me and told me how helpful those articles were. When I first joined the Association, I learned I was not the only one experiencing those problems.

You can submit technical questions on the ASA website. There is a wealth of information freely available and easily accessible covering all aspects of shotcrete on the website (Shotcrete.org). You can click on various topics or search for FAQ or past Shotcrete magazine articles. There are many resources including specification resources, a buyer's guide, safety information and shotcreter education.

Fig. 5: Workers feeding prepackaged refractory

IN THE WORDS OF SOCRATES, "ALL I KNOW IS THAT I KNOW NOTHING."

The more knowledgeable we are, the better prepared we are to succeed. We can fall into a trap when we think we know all that we need to know. There is always more to learn. New technologies emerge, new opportunities, and sometimes even new perspectives. I'm thankful for an association like ASA to help gather and capture this information, making it accessible for all with the goal of improving the application and quality of shotcrete placement around the globe.

Ted W. Sofis *recently retired as owner of Sofis Company Inc. with 47 years of experience in the shotcrete industry. He is an ACI Nozzleman Examiner and has served on the ASA Executive Board of Directors, the ASA Board, and 11 years as the Chair of ASA Publications Committee, as well as being a member on several other committees. Ted began performing shotcrete work during summers while in college from 1971 to 1974. After graduating from Muskingum College in 1975, he began full time as a nozzleman and gun operator gunning refractory in ladles and blast furnace troughs in the steel industry. Ted has worked in the shotcrete industry performing work in the power generation and steel industries, and on bridges, tunnels, dams, spillways, slope-protection, and a variety of other installations over the years.*

práctico, calificamos los procedimientos de seguridad del lanzador, la técnica de proyección y el rendimiento general en el lanzado de un panel de prueba. Los candidatos a la certificación lanzan un panel vertical y, si tienen experiencia, un panel adicional sobre cabeza. Luego, se extraen núcleos de los paneles y se califican para la evaluar la encapsulación de las barras de refuerzo incrustadas y los vacíos indeseables. Los contratistas refractarios lanzan una variedad mucho mayor de materiales que el contratista promedio de concreto lanzado. Estos materiales van desde mezclas convencionales de mezcla en seco hasta mezclas aislantes con bajo contenido de cemento y livianas. En todos los casos, hay metales insertados alrededor de los cuales se proyecta el concreto, como barras de refuerzo, anclajes refractarios de tipo V o conductos. Un lanzador experimentado de via seca necesita ajustar el aire y el agua según sea necesario. Los mismos principios se aplican ya sea que esté lanzado concreto refractarios o concreto convencional. El lanzador debe usar los ángulos de colocación adecuados, mantener la boquilla a la distancia adecuada de la superficie receptora y mantener una alta velocidad

para compactación y encapsulado adecuado. Ya sea que esté encapsulando barras de refuerzo o anclajes refractarios de tipo V, el objetivo es el mismo. Los candidatos deben aprobar tanto el examen escrito como el examen práctico para recibir la Certificación ACI de lanzadores. La certificación ACI llevada a cabo por ASA es una credencial ampliamente reconocida por ingenieros, empresas privadas y agencias públicas.

RECURSOS TÉCNICOS

ASA recopila una gran cantidad de recursos de conocimiento sobre todo lo relacionado con el concreto lanzado. Las Convenciones de ASA son solo un lugar donde se reúnen presentaciones centradas en el concreto proyectado. Recientemente, en la Convención de Concreto Lanzado en Austin, TX, asistí a una presentación donde el grupo de Marc Jolin en la Universidad Laval presentó resultados de pruebas de varias boquillas de vía seca y qué tan efectivas o ineficientes fueron y cuáles produjeron los mejores resultados. La revista Shotcrete es otro recurso valioso. A lo largo de los años, he escrito artículos en la revista Shotcrete explicando por qué los aditivos mejoradores de adherencia no son necesarios ni siquiera recomendados con la colocación de concreto lanzado. Varios contratistas se han acercado a mí y me han dicho lo útiles que fueron esos artículos. Cuando me uní por primera vez a la Asociación, descubrí que no era el único que experimentaba esos problemas.

Puedes enviar preguntas técnicas en el sitio web de ASA. Hay una gran cantidad de información disponible de forma gratuita y fácilmente accesible que cubre todos los aspectos del concreto lanzado en la página web (Shotcrete.org). Puedes hacer clic en varios temas o buscar en preguntas frecuentes o artículos pasados de la revista Shotcrete. Hay muchos recursos, incluidos recursos de especificaciones,

Fig. 5: Trabajadores alimentando refractario preenvasado

una guía de compras, información de seguridad y educación para concreteros.

EN PALABRAS DE SÓCRATES, "TODO LO QUE SÉ ES QUE NO SÉ NADA".

Cuanto más conocimiento tengamos, mejor preparados estaremos para tener éxito. Todos caemos en una trampa cuando pensamos que lo sabemos todo. Siempre hay más por aprender. Surgen nuevas tecnologías, nuevas oportunidades y, a veces, incluso nuevas perspectivas. Estoy agradecido por una asociación como ASA que ayuda a recopilar y capturar esta información, haciéndola accesible para todos con el objetivo de mejorar la aplicación y la calidad de la colocación de concreto lanzado en todo el mundo.

Ted W. Sofis *se retiró recientemente como propietario de Sofis Company Inc. con 47 años de experiencia en la industria del concreto proyectado. Es un Examinador de Concreteros ACI y ha servido en la Junta Directiva Ejecutiva de ASA, la Junta de ASA y 11 años como Presidente del Comité de Publicaciones de ASA, además de ser miembro de varios otros comités. Ted comenzó a realizar trabajos de concreto lanzado durante los veranos mientras estaba en la universidad de 1971 a 1974. Después de graduarse de Muskingum College en 1975, comenzó a tiempo completo como concretero y operador de proyección de concreto lanzado refractario en cucharas de colada y canales de altos hornos en la industria del acero. Ted ha trabajado en la industria del concreto lanzado realizando trabajos en la generación de energía y las industrias del acero, y en puentes, túneles, presas, aliviaderos, protección de taludes y una variedad de otras instalaciones a lo largo de los años.*

Synthetic Mesofibers: The Sustainable and Practical Solution for Shotcrete´s Pool Industry

By Raúl Bracamontes and Javier Busto

The construction industry has witnessed a paradigm shift in recent years with a growing emphasis on innovative materials and techniques. One such advancement that has gained significant attention is the use of synthetic fiber-reinforced shotcrete (SFRS) in the construction of swimming pools. Traditional concrete structures face challenges such as volume change due to drying shrinkage, as well as moisture and temperature variations. This article explores using synthetic fibers in shotcreted concrete, a highly versatile construction material, to enhance the durability and performance of pool structures.

Shotcrete is a placement method for concrete. It involves projecting or spraying concrete onto a surface. This makes it a popular choice for creating intricate shapes and reducing time for construction. The integration of synthetic fibers in the concrete mixture offers a promising solution to improve the performance of the pool shell. These fibers act as reinforcement to help reduce cracking and improve the strength of the structure. As we delve into the synthesis of these materials, their unique properties, and their impact on pool construction, a comprehensive understanding of the benefits and challenges associated with SFRS will emerge.

The focus of this paper extends beyond the technical aspects of SFRS and delves into its practical applications in pool design and construction. Examining real-world case studies, we will explore how this innovative construction approach contributes to the longevity and sustainability of pool structures. Additionally, considerations such as cost-effectiveness, environmental impact, and maintenance will be addressed, providing a holistic perspective on the feasibility and desirability of adopting SFRS in the construction of today's swimming pools. In exploring the use of SFRS, we aim to contribute valuable insights to the evolving landscape of construction materials and methodologies by fostering advancements that meet the demands of a dynamic and forward-thinking industry.

Fiber-reinforced concrete (FRC) is a type of concrete that incorporates discrete fibers to enhance its structural properties. Adding fibers, such as steel, glass, synthetic, or natural fibers, provides improved toughness, durability, and crack resistance (residual strength) to the concrete matrix. These fibers act as a reinforcement mechanism by distributing and helping to restrain cracks due to various factors like shrinkage, temperature changes, or applied loads.

Improved residual strength and toughness are key mechanical properties in FRC, contributing to enhanced performance of concrete structures, especially after the onset of cracking. Residual strength refers to the ability of a material (in this case, concrete) to carry loads even after the formation of cracks. In FRC, fibers provide a bridging effect across cracks, preventing them from widening and improving the material's post-cracking load-carrying performance. This bridging action allows FRC to maintain a significant portion of its load-carrying capacity even in the presence of cracks, which leads to improved structural reliability and durability.

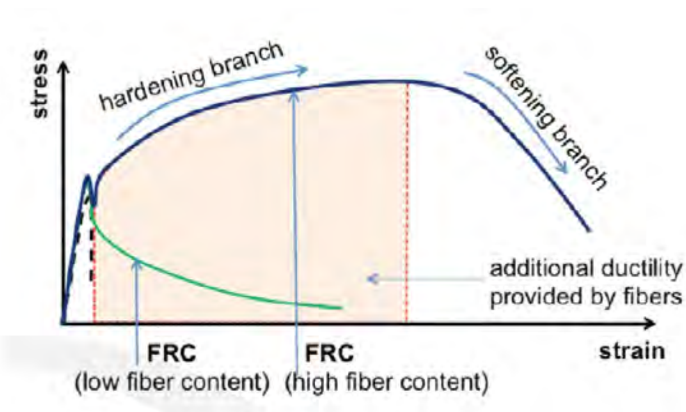

Fig 1: Concrete ductility increased by using fiber

Toughness in FRC refers to the material's ability to absorb energy and deform plastically before failure. Fibers dispersed in the concrete matrix act as reinforcement and create a network that resists crack propagation and enhances the overall toughness of the material. The improved toughness of FRC yields structures that can better withstand dynamic loading, impact, and cyclic loading conditions. This characteristic is particularly beneficial in applications where resistance to cracking and enhanced energy absorption are critical, such as earthquake-prone or high-impact areas.

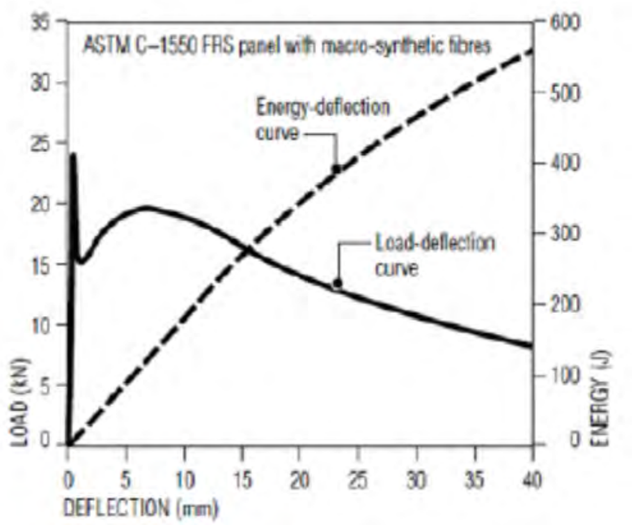

Fig 2: ASTM C1550 test results showing FRC energy absorption

The combination of residual strength and toughness in FRC is a significant benefit over traditional concrete. While traditional concrete may exhibit brittle behavior after cracking, FRC maintains a higher degree of structural integrity and continues to carry loads, which mitigates the risk of sudden and catastrophic failure. These properties make fiber-reinforced concrete a valuable material for a wide range of applications, including any type of shotcrete applications: tunneling, slopes, canals, and pools, where improved durability and structural performance are essential considerations.

One phenomenon associated with the incorporation of fibers in concrete is the "fiber balling effect." This occurs during the mixing process when the fibers clump together and form small balls or clusters. Fiber balling can hinder the uniform distribution of fibers throughout the concrete mix, potentially leading to variations in mechanical properties and compromising the intended purpose of the fiber reinforcement. To mitigate this effect, proper mixture design, mixing techniques, and the length and form of the fiber are essential when you are planning to use a high dosage of fibers to comply with certain toughness requirements.

This paper provides a conceptual study of four types of pool structural designs with a proposal for substituting the area of steel provided by steel reinforcing bars with a new type of synthetic fiber, sustainable mesofibers, that will provide increased durability, lower cost, easier finishing, and a significant reduction in CO_2 emissions.

Let's consider a theoretical structural design of a concrete pool with a 6 in. (150 mm) wall reinforced with #3 and #4 (#10M and #13M) rebar spaced at 12 in. (300 mm) in one or two layers.

The following table refers to the area of steel in these traditional designs for the 6 inches thickness (h), from higher to lower ratios (p):

Steel Rebar Fy 60,000 psi (410 MPa)	Steel Ratio (p)
Rebar #3 @ 12 in. (single)	0.158%
Rebar #4 @ 12 in. (single)	0.280%
Rebar #3 @ 12 in. (double)	0.316%
Rebar #4 @ 12 in. (double)	0.560%

To propose a dosage of synthetic structural fiber to substitute for these steel ratios, we are going to use the ACI 544.4-18 Chapter 4 method[1], where you must consider the following equation to provide the same level of crack control as Grade 60 steel:

Tensile force provided by steel = $\mathbf{F_{ts}} = \boldsymbol{p^{*}F_y}$

$\boldsymbol{p}$ = steel ratio

Considering the allowable tension stress from steel reinforcement as, $\mathbf{F_{ws}}$:

$$\mathbf{F_{ws}} = 0.667^{*}\mathbf{F_{ts}}$$

And that the flexural residual strength of the FRC, $\mathbf{f_{e3}}$, is:

$$\mathbf{f_{e3}} = \mathbf{F_{ws}} \,/\, 0.37$$

For the traditional rebar-reinforced pools, this table shows the tensile and flexural residual strengths achievable for FRC to provide equivalent crack control to the shotcrete wall:

Steel Rebar Fy 60,000 psi	Steel Ratio (p)	Tensile Force Provided by Steel (F_{ts})	Allowable Tensile Stress (F_{ws})	FRC Flexural Residual Strength (f_{e3})
Rebar #3 @ 12 in. (single)	0.158%	94 psi (0.65 Mpa)	63 psi (0.43 Mpa)	170 psi (1.17 Mpa)
Rebar #4 @ 12in (single)	0.280%	167 psi (1.15 Mpa)	112 psi (0.77 Mpa)	302 psi (2.08 Mpa)
Rebar #3 @ 12in (double)	0.316%	189 psi (1.30 Mpa)	126 psi (0.87 Mpa)	340 psi (2.34 Mpa)
Rebar #4 @ 12in (double)	0.560%	335 psi (2.31 Mpa)	223 psi (1.54 Mpa)	603 psi (4.16 Mpa)

Before providing a table of dosages for synthetic mesofiber that will result in the desired flexural residual strength, let's look at why using these types of fibers is desirable.

What are synthetic structural mesofibers and what are the differences between microfibers and macrofibers routinely used today?

Synthetic mesofibers for concrete are fibers that fall between macrofibers and microfibers in size and aspect ratio. These mesofibers are typically shorter than macrofibers but longer than microfibers, and they are designed to enhance the performance of concrete in terms of toughness, crack resistance, and durability similar to macrofibers.

MACROFIBERS:

Size and Aspect Ratio: Macrofibers are relatively large fibers, typically exceeding 0.012 in. (0.3 mm) in diameter. They can be 0.5 to 2.5 in. (12 to 63 mm) in length with aspect ratios (length to diameter ratio) ranging from 30 to 100.

Applications: Macrofibers are commonly used to provide post-cracking reinforcement in concrete. They effectively control crack widths and improve toughness in applications such as industrial floors, pavements, and shotcrete.

MICROFIBERS:

Size and Aspect Ratio: Microfibers are significantly smaller than macrofibers with diameters generally less than 0.012 in. They are short fibers and typically range from 0.125 to 2 in. (3 to 50 mm) in length with lower aspect ratios compared to macrofibers.

Applications: Microfibers are often used to control early-age plastic shrinkage cracking in concrete. They effectively prevent the formation of small cracks during the early stages of concrete hardening. Polypropylene and glass microfibers are common types used in concrete mixes.

MESOFIBERS:

Size and Aspect Ratio: Mesofibers fall in between macrofibers and microfibers in terms of size and aspect ratio. The diameters and lengths of mesofibers can vary, and they provide a balance between the benefits of macrofibers and microfibers.

Applications: Mesofibers are designed to offer a combination of post-cracking performance and early-age crack control. They are suitable for applications where a balance between crack resistance and workability is desired, such as in various types of structural and non-structural concrete elements.

Common synthetic mesofibers include polypropylene, polyethylene, and nylon fibers. These fibers contribute to the performance of concrete by improving its resistance to cracking and enhancing durability, which makes them valuable additives in concrete mixes.

Fig 3: Typical synthetic microfibers, mesofibers and macrofibers

IMPORTANCE OF ADHESION BY STRUCTURAL FIBERS WITH MECHANICAL ANCHORAGE VS. SMOOTH FIBERS

In the fiber-reinforced concrete industry, a wide variety of macrofibers and mesofibers can be found. However, just as not all have the same tensile strengths and elastic modulus, they also have different shapes or geometries. The anchorage of synthetic macrofibers or mesofibers within the concrete paste is crucial to creating a ductile and tough material, as shown in the following graph:

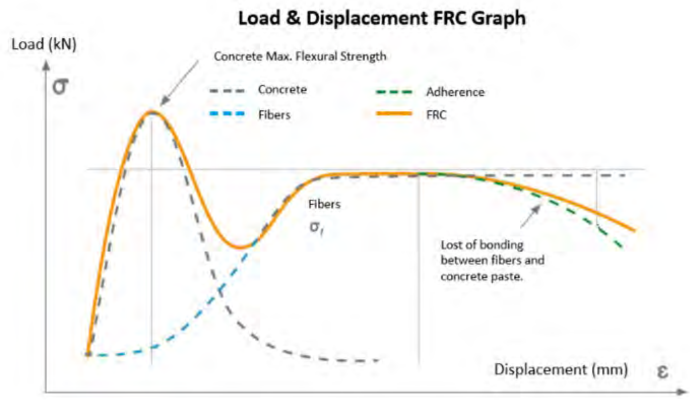

Fig 4: Ability of FRC to carry post-cracking load

The strength provided by macrofibers or mesofibers is residual, which means that once the concrete reaches its maximum load, it will fail suddenly if it does not have reinforcement at the crack location. This is where the union of the concrete paste and synthetic macrofibers or mesofibers come into play. As displayed in the graph, the ductility will depend on the loss of fiber anchorage. Hence, the importance of the geometry of the synthetic fibers to continue to safely support the imposed loads in our concrete structures and increasing the lifespan of the constructed structure.

The geometry of macrofibers or mesofibers was studied in the thesis of Civil Engineer, David Joseph Carnovale: "Behavior and Analysis of Fiber-Reinforced Concrete with Steel and Macro synthetic Fibers Subjected to Inverted Cyclic Loading: Pilot Research" from the University of Toronto[2]. In this thesis, the table below discusses Tb = Fiber anchorage resistance (MPa):

Table 2.4: Bond Strengths of Macro-Synthetic Fibres with Mechanical Anchorages (Won et al., 2006)

Mechanical Anchorage Type	τ_b [MPa]	$\tau_b / \tau_{b,sraight}$
Straight	0.28	1.00
Crimped	1.82	6.50
Twisted	0.56	2.00
Enlarged Ends	0.71	2.54
Sinusoidal Ends	0.72	2.57
End-Hooked	0.40	1.43
Double Duoform	1.10	3.93

Fig 5: Bond strength of synthetic macrofibers with mechanical anchorages

Won et al. (2006)[3] conducted a series of extraction tests on monofilament synthetic macrofibers with different types of mechanical anchors. The bonding forces improved significantly compared to a straight and smooth synthetic macrofiber against a corrugated synthetic macrofiber by a factor of 650%. There was also a much higher adhesion, Tb, compared to sinusoidal (zigzag) fibers, exceeding 250%.

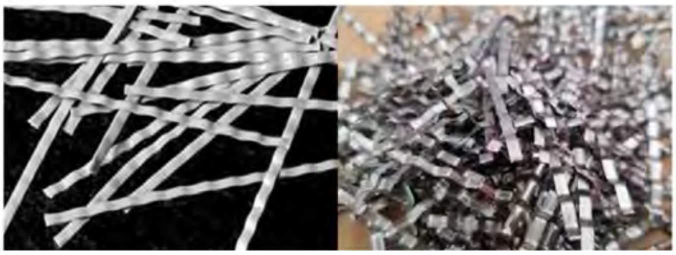

Fig 6: Sinusoidal synthetic and steel fibers

Later, Choi et al. (2012)[4] studied what would happen with the cross-sectional area of the macrofiber and re-evaluated Tb = Fiber anchorage resistance (MPa) with different shapes (clover, cross, star, and hexagram) of smooth and corrugated fibers.

Table 2.5: Bond Strengths of Macro-Synthetic Fibres with Varying Cross Sections (Choi et al., 2012)

Cross Section	$SA^{*}/SA_{circular\ fibre}$	$\tau_{b,straight}$ [MPa]	$\tau_{b,crimped}$ [MPa]
Clover	1.11	0.37	3.38
Cross	1.48	0.49	3.23
Star	1.51	0.43	2.69
Hexagram	1.73	0.48	4.13

* SA is the fibre surface area

Fig 7: Bond strength of synthetic macrofibers with varying cross sections

Again, the conclusion was that corrugated fibers, with the same cross-sectional area, had much higher Tb resistance in MPa and an 860% higher mechanical resistance to anchorage failure with the concrete paste.

The following image represents types of smooth synthetic macrofibers and mesofibers with a rectangular (closest to hexagonal) shape from the international market:

Fig 8: Smooth synthetic fibers with a rectangular shape

For this study we have chosen synthetic mesofibers with cross-sectional geometries closest to a hexagram and crimped-embossed "rod-type" mechanical anchors. Looking towards a more sustainable path, these synthetic mesofibers were manufactured as a 100% recycled polypropylene blend and designed to meet the minimum tensile strength required in ACI 544.4R-18 for being considered a structural concrete fiber.

Fig 9: The mesofiber selected for this study

These geometries gave us the most ductile residual strength and toughness results with curves in load-deformation graphs without loss of anchorage adherence, even at deformations of 1.6 in. (40 mm) in the ASTM C1550[5] test and surpassing the concrete maximum flexural strength at deformations of 0.12 in. (3.0 mm) with the ASTM C1609[6] test. These graphs include some of the dosages proposed for mesofiber:

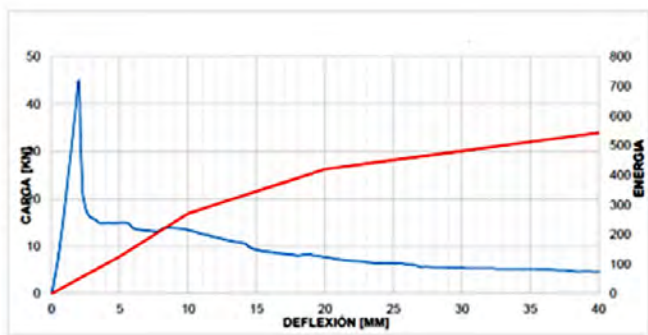

Fig 10: Results of an ASTM C1550 test with mesofibers

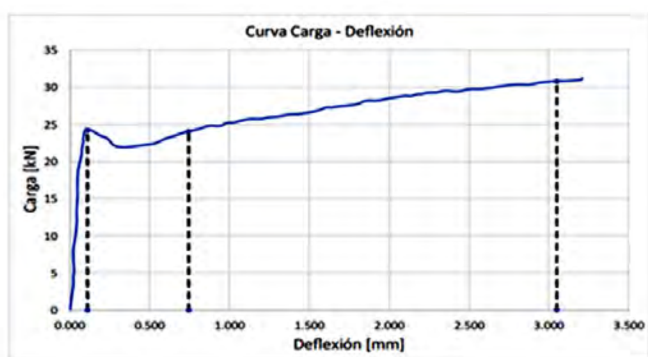

Fig 11: Results of an ASTM C1609 test with mesofibers

After identifying the characteristics for the type of structural fiber we needed for this evaluation, below are the dosages of the synthetic mesofiber that will meet with the desired reinforcing steel ratios and replace the steel reinforcement in pool walls, specifically of 6 in. width.

Steel Rebar Fy 60,000 psi	Steel Ratio (p)	Dosage: Synthetic Mesofiber Lb/yd³ (Kg/m³)
Rebar #3 @ 12in (single)	0.158%	7.0 (4.2)
Rebar #4 @ 12in (single)	0.280%	12.0 (7.2)
Rebar #3 @ 12in (double)	0.316%	14.0 (8.4)
Rebar #4 @ 12in (double)	0.560%	24.0 (14.4)

Fibers may exhibit impressive performance in laboratory assessments but can pose significant challenges when applied in real-world construction settings. Achieving a harmonious balance between these two aspects is crucial. Various fibers come with distinct protocols regarding their optimal inclusion in concrete and specific time requirements for the addition process. The addition of fibers in a manner resembling "chicken feed" can be cumbersome for concrete producers, especially in high-speed mixing systems used in paving applications and applications needing with elevated fiber dosages.

Fig 12: Balling up of fibers introduced into a concrete mixture

The potential for fibers to form balls and clump together presents substantial issues during shotcrete placement, and this impacts processes such as pumping and finishing. Ensuring a uniformly distributed network of fibers throughout the concrete is paramount for performance and crack control. Fiber balls pose challenges at the job site and lead to an overall reduction in the effective fiber dosage whenever a ball is removed from the slab. Additionally, hidden fiber balls within the slab may pose future risks, potentially causing soft spots, leakage and even structural failure.

The significance of the mixture design cannot be understated in addressing the fiber balling issue. However, with the use of synthetic mesofibers, many of these concerns can be mitigated or even eliminated. The inherent characteristics of mesofibers, including their length, aspect ratio, surface properties, and compatibility contribute to a more controlled and uniform dispersion within the concrete mixture, and this minimizes the risk of fiber balling. This gives synthetic mesofibers an advantage in enhancing the performance and durability of concrete structures.

THE SUSTAINABILITY OF USING SYNTHETIC MESOFIBERS WITH 100% RECYCLED POLYPROPYLENE BLEND

The use of synthetic mesofibers in concrete, particularly those manufactured from 100% recycled materials, is often considered more sustainable than the use of steel reinforcement. One key factor contributing to this sustainability is the environmental impact associated with steel production. The manufacturing of steel involves significant energy consumption and the release of carbon dioxide emissions, which contributes to a substantial carbon footprint. In contrast, mesofibers produced from recycled materials require less energy and help divert waste from landfills, which aligns with the principles of recycling and resource conservation.

Another aspect of sustainability in favor of synthetic mesofibers is their resistance to corrosion. Steel reinforcement in concrete structures is susceptible to corrosion over time, especially in harsh environmental conditions. This leads to degradation and maintenance issues. Corrosion not only compromises the structural integrity of the concrete but also requires additional resources for repair and replacement. Mesofibers, being synthetic in nature, do not corrode and offer long-term durability without the need for constant maintenance. Therefore, they reduce the overall environmental impact because of the extended life with lower maintenance of the structure.

1. Steel-Rebar Kg CO_2eq/Kg:

Reinforcement Consideration No.	Steel-Rebar Mesh	Steel* Kg / m²	Steel Kg CO_2eq/Kg	Kg CO_2eq/m²	m² / pool**	Steel Kg CO_2eq/Pool
1	Var #3 @ 12 in. (single layer)	3.73	2.06	7.68	200 (2200 ft²)	1,536
2	Var #4 @ 12 in. (single layer)	6.63		13.67		2,734
2	Var #3 @ 12 in. (double layer)	7.47		15.38		3,072
4	Var #4 @ 12 in. (double layer)	13.25		27.31		5,468

**Considering the #3 has a 0.375 in. diameter with 0.56 Kg/m and the #4 has a 0.5 in. (13 mm) diameter with 0.994 Kg/m.*
***Considering a 200 m² pool-wall (2200 ft²) with 6 in. width, that will consume 30 m³ (39 yd³) of shotcrete.*

2. 100% Recycled Polypropylene Structural Mesofiber Kg CO_2eq/Kg:

Considerations for the 100% recycled polypropylene mesofiber:

Manufacturing Stage of Sustainable MesofibersSteel* Kg / m^2		
A1	Raw material "sustainable polypropylene"	**0.18 Kg CO_2eq/Kg**
A2	Raw material transport	**0.04 Kg CO_2eq/Kg**
A3	Mesofibers manufacture	**0.54 Kg CO_2eq/Kg**
Total Kg CO_2eq/Kg "Sustainable Mesofiber"		**0.76 Kg CO_2eq/Kg**

Reinforcement Consideration No.	Mesofiber Dosage (Kg/m^3)	Mesofiber Kg / m^2	Mesofiber Kg CO_2eq/Kg	Kg CO_2eq/m_2	m^2 / pool*	Mesofiber Kg CO_2eq/Pool
1	4.2 (7.0 Lb/yd^3)	0.63	0.76	0.48	200 (2200 ft^2)	96
2	7.2 (12.0 Lb/yd^3)	1.08		0.82		164
3	8.4 (14.0 Lb/yd^3)	1.26		0.96		192
4	14.4 (24.0 Lb/yd^3)	2.16		1.64		328

**Considering a 200m^2 pool-wall (2200 ft^2) with 6in. width, that will consume 30m^3 (39 yd^3) of shotcrete.*

2. Comparing the Steel-Rebar vs the Sustainable Mesofiber Kg CO2eq/Kg tables:

Reinforcement Consideration No.	Steel-Rebar Kg CO_2eq/Pool	Mesofiber Kg CO_2eq/Pool
1	1,536	96
2	2,734	164
3	3,072	192
4	5,468	328

Additionally, the light weight of synthetic mesofibers yields reduced transportation costs and emissions during construction, further enhancing their environmental benefit. As sustainable construction practices gain prominence, the utilization of synthetic mesofibers emerges as an eco-friendly alternative while promoting a more resilient and environmentally-conscious approach to concrete reinforcement compared to traditional steel reinforcement.

COST BENEFIT BETWEEN INSTALLING STEEL REBAR MESH VS. ADDING SUSTAINABLE MESOFIBERS TO A SHOTCRETE MIX

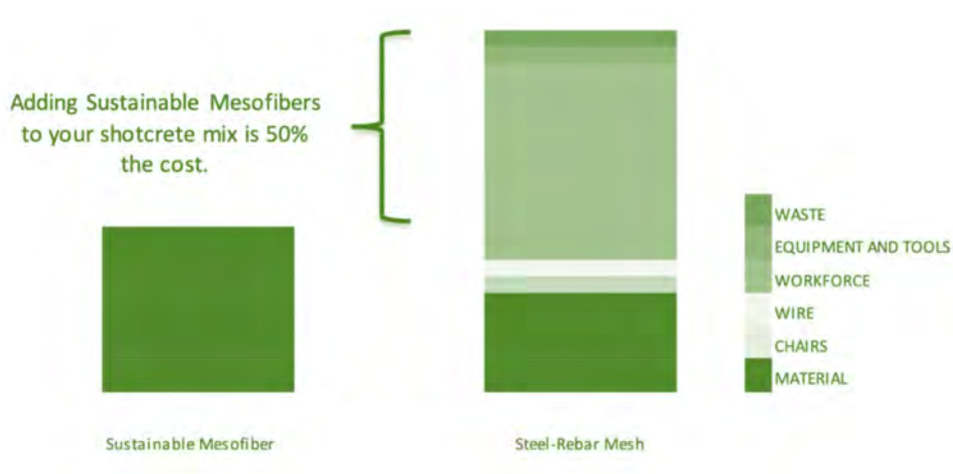

Fig 13: Sustainability benefits of mesofibers compared to traditional reinforcing steel

PROCEDURE TO CONSTRUCT A CONCRETE SWIMMING POOL

Constructing an in-ground concrete swimming pool involves a series of well-defined steps to ensure durability, functionality, and aesthetics. Below is a detailed procedure outlining each stage of the construction process:

Step 1: Selection of Location and Design

The initial phase of constructing a concrete swimming pool is to select an appropriate location and design. Factors such as the shape, depth, area, filtration system, and overall size of the pool are considered. The chosen location should facilitate easy maintenance and be situated away from trees to prevent leaves from falling into the pool. Additionally, the orientation of the pool should maximize exposure to sunlight.

Step 2: Excavation of Earth

Following the design selection, the construction process begins with excavating the designated area for the pool. Wooden stakes are used to mark the perimeter of the pool, and earth removal equipment, such as a backhoe, is employed to dig within the marked boundaries. Care is taken to avoid any underground utilities or drainage lines during excavation.

Step 3: Construction of Swimming Pool Base

The construction of a sturdy base is crucial for the longevity of the swimming pool. After excavation, the area is filled and compacted with firm soil or gravel to create a level surface. A layer of lean concrete can be poured onto the compacted base, ensuring uniformity and strength. Proper drainage slopes are incorporated into the base design to facilitate water flow to the filtration system.

Step 4: Shotcrete Reinforcement

Steel Cage Reinforcement

Steel reinforcement is installed along the pool walls and floor to provide structural integrity. The reinforcement is designed and laid out for shotcrete placement. Using shotcrete placement creates a seamless structure without joints between the walls and floor. Plumbing lines and drainage systems are integrated within the steel cage arrangement or outside the wall to support water circulation.

Fiber-reinforced-shotcrete

Using SFRS for pool construction offers several advantages over traditional steel reinforcement. Firstly, the installation of steel reinforcing bar in shotcrete pool construction is a time-consuming process. The placement of each rebar requires close attention to detail and can slow down the construction timeline significantly. Moreover, ensuring that the reinforcing bars are perfectly positioned and rigidly secured within the wall is challenging and often results in less-than-optimal reinforcement. This inefficiency not only prolongs the construction schedule but also introduces the potential risk of structural weaknesses due to improperly placed or misplaced rebars.

On the other hand, synthetic fibers provide a more efficient and cost-effective solution for reinforcing shotcrete pools. These fibers are easily mixed into the concrete mixture, which eliminates the need for time-consuming placement of individual reinforcing bars. Once added into the mixture, the fibers uniformly distribute throughout the concrete and provide consistent reinforcement without the risk of misplacement. Additionally, using synthetic fibers reduces labor costs associated with the reinforcing bar installation and minimizes material waste, contributing to overall cost savings in the construction. Furthermore, synthetic fibers offer enhanced crack resistance and durability, providing longevity and structural integrity of the shotcrete pool shell over time. Overall, the adoption of synthetic fibers presents a practical and advantageous alternative to traditional rebar reinforcement in shotcrete pool construction.

Step 5: Pump and Filter System for Swimming Pool

A pump and filter system are installed to maintain water circulation and cleanliness. Plumbing connections are made to facilitate water flow from the pool to the filtration system and back. Additionally, provisions are made to replenish water lost through evaporation or splashing.

Step 6: Concreting in Swimming Pool Construction

The walls and floor of the pool are constructed using shotcrete placement, which will ensure uniformity and strength. Specialized finishing tools are used to shape the concrete surface to meet the design specifications. Following concrete placement, curing is performed for a period of two weeks to enhance strength, watertightness and durability.

Step 7: Plastering and Tiling of the Concrete Pool

Once the shotcreted pool shell is cured, specialty plaster coatings are often applied. These give a more uniform color and texture to the pool's inner surface. Many pools will have portions of the shotcreted pool shell tiled for a distinctive appearance and ease of cleaning.

Step 8: Construction of Coping

Coping, the perimeter around the pool edge, is constructed using materials such as concrete, marble, or tile. A waiting period of two to three days is observed after coping construction before filling the pool with water.

Step 9: Pool Start-Up

Once construction is complete, the pool undergoes a start-up phase to ensure proper functionality. This involves testing the circulation system, installing additional features, balancing water chemistry, and cleaning the pool and surrounding areas.

Step 10: Final Coating of the Deck and Landscaping Begins

The deck surrounding the pool may receive a final coating to enhance aesthetics and durability. Following deck completion, landscaping is often installed to integrate the pool seamlessly into the surrounding environment.

CONCLUSIONS

In conclusion, the integration of synthetic mesofibers into shotcrete for pool construction represents a significant advancement in the field of concrete materials and methodologies. This paradigm shift addresses one of the challenges faced by traditional concrete structures - cracking, that may be particularly evident in environments with fluctuating temperatures and moisture levels. These fibers act as reinforcements by improving the post-cracking performance of shotcrete and maintaining a significant portion of its load-carrying capacity even in the presence of cracks. Using synthetic mesofibers in shotcrete enhances the durability and performance of pool structures and offers a sustainable and practical solution.

The environmental benefits of using synthetic mesofibers are notable. The reduction in CO_2 emissions associated with producing and using these sustainable fibers presents a compelling reason for their adoption. Traditional steel reinforcement, with its significant carbon footprint and susceptibility to corrosion, can be effectively replaced by synthetic recycled mesofibers aligning with the principles of sustainability and environmental responsibility.

The study also addresses the economic aspect by demonstrating that the use of synthetic mesofibers is not only environmentally friendly but also cost-effective. The proposed dosages of synthetic mesofibers, based on the ACI 544.4-18 methodology, show promising results in terms of crack control and flexural residual strength. These dosages, when compared to traditional steel ratios, indicate a viable and economical alternative for pool construction with potential cost savings.

Additionally, the ease of handling and application of synthetic mesofibers adds to their practicality in construction, especially in scenarios where acquiring traditional materials like reinforcing steel can be challenging. The controlled dispersion of mesofibers within the concrete mix minimizes issues such as fiber balling, ensuring uniform distribution and improving the overall performance of the shotcrete.

In summary, the use of synthetic sustainable mesofibers in shotcrete for pool construction offers a holistic solution that addresses technical, environmental, and economic considerations. This innovative approach contributes to the evolving landscape of construction materials, fostering advancements that meet the demands of a dynamic and forward-thinking industry. The transition from traditional concrete reinforced with steel to shotcrete incorporating synthetic mesofibers represents a sustainable and practical evolution in the construction of modern swimming pools.

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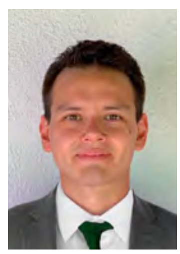

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Mount Pleasant Station Part 2: Construction Phase

By Shaun Radomski; Dudley R. (Rusty) Morgan, Ph.D., F.ACI; Lloyd Keller, F.ACI; Daniel Sanchez; & Laura Di Monte

Based on successfully addressing all the preconstruction issues raised in the article, "Mount Pleasant Station, Part 1: Preconstruction Qualification for Shotcreting of Mass Concrete" from the Q4 2023 issue of *Shotcrete* magazine, the joint venture consortium, Crosslinx Transit Solutions (CTS), designers, and constructors of the Mount Pleasant Station on the Eglinton Crosstown Light Rapid Transit Line in Toronto, proceeded with using a low carbon, low heat of hydration 70% slag concrete mixture for shotcrete placement of the structural mass concrete perimeter walls at this station. This second part of the article details the construction phase of the Mount Pleasant Station and includes details of the following:

1. Typical station structural wall design details
2. Shotcrete equipment used on the project, including set-up and staging
3. Shotcrete construction sequencing and productivity and challenges to overcome while shooting the work
4. Shotcrete supply, pumping, application, finishing and curing/protection
5. Quality control inspections and test records including results of compressive strength and thermal monitoring
6. Examples of partially constructed and completed structural shotcrete walls

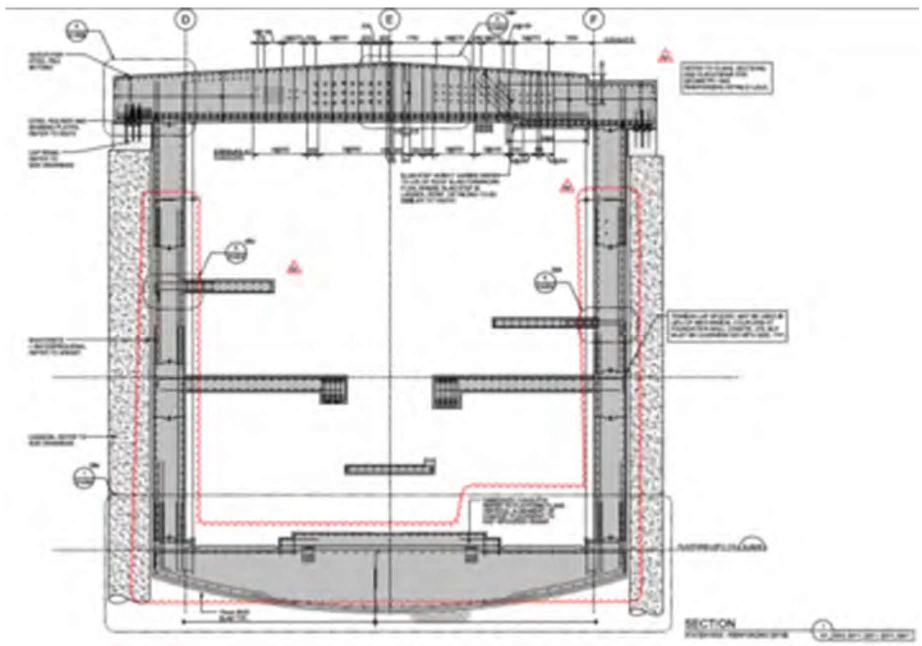

Fig. 1: Typical 1.3 m thick perimeter station wall details that were constructed using shotcrete. Note: Invert slabs were constructed using cast-in-place-concrete methods.

TYPICAL STRUCTURAL WALL DESIGN DETAILS

Fig. 1 shows a typical 1.3 m (4.3 ft) thick heavily reinforced perimeter wall detail at Mount Pleasant Station. Figures 2a-2c show Mount Pleasant Station under construction, including the following: top-down excavation and dismantling of pre-cast tunnel segments (Fig. 2a), sheet waterproofing membrane installation and invert slab construction (Fig. 2b), and shotcrete wall construction at the tunnel openings (Fig. 2c).

SHOTCRETE EQUIPMENT, SET-UP, AND STAGING

One typical set of shotcrete equipment included a 41 m^3/hr Reed C50SS pump (Fig. 3) and two 10.6 m^3/min (375 ft^3/min) 375H air compressors. Shotcrete was pumped from the hopper into a 90° steel elbow with an initial inside diameter of 125 mm (5 in.). Following the 90° steel elbow, the inside diameter of the steel line was reduced to 100 mm (4 in.) and then gradually reduced to 75 mm (3 in.). Up to 22 m (70 ft) of 75 mm (3 in.) diameter steel slick line was used to feed shotcrete down a large vertical drop. The steel line contained several turns and 90° elbows to reach the station box track platform from street level (Fig. 4). The steel line transitioned into 50 mm (2 in.) internal diameter hoses with 8.5 MPa (1200 psi) pressure rating at the shotcrete work area (Fig. 5). At times, shotcrete was pumped a total length of approximately 90 m (300 ft) to the work area. All connections in the shotcrete delivery system used clamp gaskets and rubber seals.

Fig. 2a: Top-down excavation and dismantling of precast tunnel segments.

Fig. 2b: Sheet waterproofing membrane installation and invert slab construction.

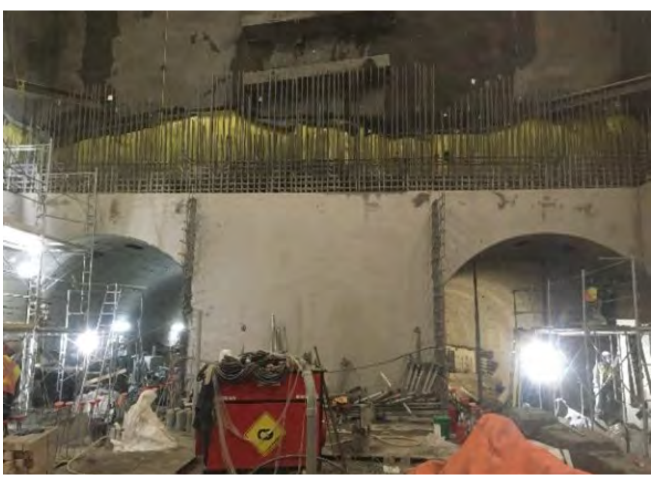

Fig. 2c: Shotcrete wall construction at tunnel openings.

The nozzle assembly (Fig. 5) utilized the following:

- A unique pipe extension to reduce the shooting distance to the receiving surface at the back of the wall
- A rubber nozzle tip wrapped with duct tape to reduce bulging of the nozzle tip during bench shooting, which provided the shotcrete with a more concentrated shotcrete stream and a "rifling" type action

Compressed air was fed to the nozzle assembly using 30 mm (1.2 in.) inside diameter air delivery hoses with 2.8 MPa (400 psi) pressure rating. A separate air compressor fed compressed air to two blow pipes (Fig. 6). The reason for the separate compressor was to avoid stealing any air from the nozzle during bench shooting and blow piping simultaneously. A long stiff rod 40 mm (1.6 in.) diameter vibrator (Fig. 7) provided the placed shotcrete with supplementary consolidation. Scaffolding was used to provide shotcreter, crew, and inspectors with clear and safe access to the work, including adequate access/egress (i.e. ladders), and the set up was signed off with green safety tags (Fig. 8) prior to each day's shotcrete shooting, indicating the scaffold was safe to use.

Fig. 3: Reed C50SS Shotcrete Pump.

Fig. 4: Steel Delivery Line entering station box to reach the track platform invert slab using several bends and 90° elbow connections.

Fig. 5: Green Line G783-200 Fabric Concrete Placement Hose connected to a nozzle assembly utilizing a unique pipe.

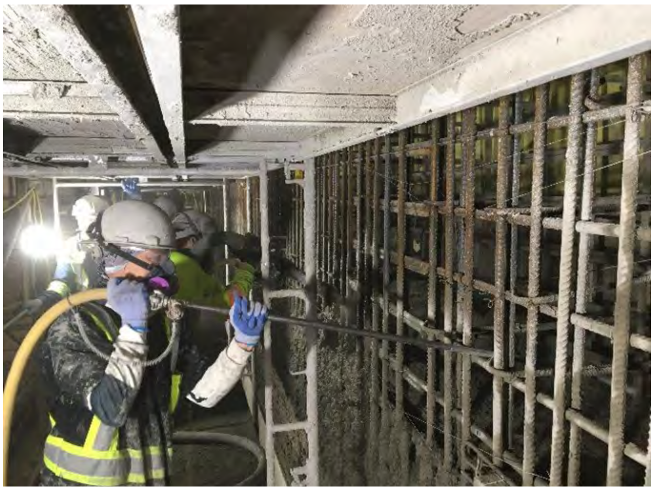

Fig. 6: Compressed air blow pipe working in tandem with shotcreter during bench shooting.

Fig. 7: A long 40 mm (1.6 in.) diameter stiff rod vibrator for supplemental consolidation. Credit: Jimmy Wang.

Fig. 8: Scaffold sign off indicating safe to use. Credit: Robert Mattes.

SHOTCRETE CONSTRUCTION SEQUENCING, PRODUCTIVITY, AND CONSTRUCTION CHALLENGES TO OVERCOME WHILE SHOOTING THE WORK

CTS began shotcrete construction on July 29, 2020, in the Secondary Entrance on the East side of Mount Pleasant Rd. three (3) levels below Eglinton Avenue. Shotcrete construction was finished in the Secondary Entrance on December 21, 2020. On October 20, 2020, shotcrete construction began in the station box (four levels below Eglinton Avenue) with the construction of the 1.5 m (4.9 ft) thick West Headwall tunnel openings. CTS subdivided the station box into five segments which were designated (from West to East) as Box 1, Box 2, Box 3, Box 4, and Box 5. Construction progressed with building of the 1.3 to 1.5 m thick North and South perimeter walls of each station box, as well as the East Headwall tunnel openings. Shotcrete was used to construct the station walls in four approximately 7 m (23 ft) high lifts, right up to the underside of the roof (i.e. the top lift). Shotcrete construction was finished in the station box on October 19, 2021. Similar to the secondary entrance mentioned earlier, construction of the Main Entrance on the West side of Mount Pleasant Rd. began on May 7, 2021 and was finished on December 11, 2021. Up to 224 m^3 (290 yd^3) of concrete was shotcreted in a single day using two pumps and shotcrete crews. Shotcrete was placed at up to 15 to 20 m^3/hr (20 to 26 yd^3/hr) during peak production. A total of 7187 m^3 (9400 yd^3) of shotcrete was used to construct the station walls, and Figure 9 shows shows and example of a large production shoots at Mount Pleasant Station. Figures 10a and 11b show construction of the station walls right to the underside of the roof.

Fig. 9: Large shotcrete volumes of up to 224 m^3 were applied in a single day of production at Mt Pleasant Station in Toronto using two pumps and shotcrete crews.

Fig. 10a: A 300 mm (12 in.) wide StayForm positioned 450 mm (18 in.) from front inner wall face.

Fig. 10b: Shooting to the StayForm and out to cover the front reinforcing steel and up to the roof.

WATERPROOFING SYSTEM

The waterproofing system for these walls was designed with a post curtain wall grouting capability (Figs. 11a, 11b, and 12). This process required the use of many individual grout tubes that were connected to grout injection boxes that were installed along the inner wall face (Fig. 11b). These tubes were affixed through the wall and into the sheet waterproofing membrane at various points along the membrane waterproofing system. Affixing the grout tubes so that these tubes were not loose and floppy during shotcrete application and avoiding multiple grout tube bundles was reviewed continuously by CTS and the shotcrete inspector. It was prudent that the sheet waterproofing membrane was installed so that the membrane was bonded to the vertical face of the excavation to avoid a "trampoline effect" occurring during bench shooting, which can potentially reduce shotcrete confinement at the membrane interface and increase the risk for passage of moisture afterwards (Ref. 7).

WALL ANCHORING AND BRACING SYSTEM

A BA Anchoring system was used to brace the wall against forward toppling motion (Figs. 11a and 12). BA Anchors were drilled through the caisson piles behind the sheet membrane along the perimeter of the station at approximately 1.83 m (6 ft) O.C. and were affixed to the heavy rebar cage by tie wire and by splicing hook bars to the anchor rods connecting the back mat of reinforcing steel to the front mat of reinforcing steel using the hooked ends wrapping around the front mat of reinforcing steel (Fig. 12). This level of bracing was observed to successfully secure the wall against forward movement and vibration during shotcrete application. It was critical to ensure that the wall rebar was braced against forward toppling, and to limit any movement or vibration during shotcrete application for safety, wall alignment, and overall quality of shotcrete around rebar and confinement of shotcrete at the back membrane. Securing the wall was continuously reviewed by CTS and the shotcrete inspector several days in advance of the scheduled shotcrete application.

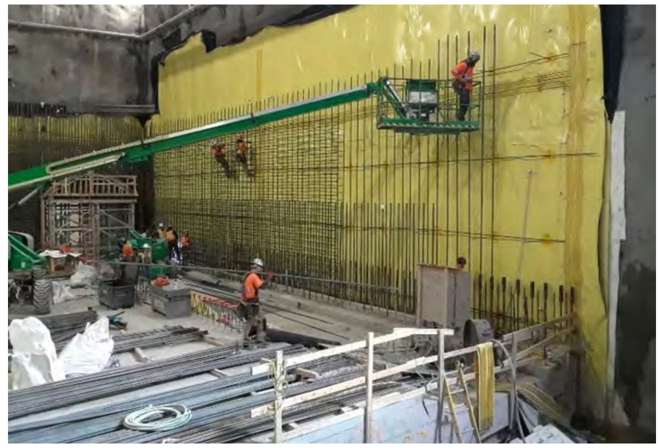

Fig. 11a: Waterproofing sheet membrane in-place for 1.3 m thick perimeter walls in station box. Rebar fastened to BA anchors spaced at 1.8 m (6 ft) (blue arrows).

Fig. 11b: Waterproofing system consisted of a post curtain wall grouting capability and many grout tubes and injection boxes fastened to the reinforcing steel.

Fig. 12: A BA Anchor (red arrow) and rod spliced to a hook bar is shown and was used to brace the wall to resist forward toppling.

REINFORCING STEEL

Affixing of rebar to reduce multiple bundles of lapped bars (Fig. 13) was continuously reviewed by CTS and the shotcrete inspector as bundles of rebar can hinder the nozzleman from being able to insert the nozzle through the openings in the front mat of rebar. Access for inserting the nozzle through the front rebar was important to reduce the shooting distance to the back mat of rebar to significantly decrease the likelihood of shadows forming behind the back rebar from lower impact velocity. Repositioning the rebar in a back-to-front orientation was considered by CTS to increase the size of the openings in the front reinforcing mat. This allowed the shotcreter to fully insert the nozzle with the pipe extension during bench shooting and reduce the shooting distance. The reduced distance increased the shotcrete's impact velocity, and improved consolidation of the concrete in place. Vibrators were carefully used to enhance the consolidation of the shotcrete around the back rebar and to the outer waterproofing membrane.

The back mat of rebar was spaced off the outer membrane using metal chairs with plastic tips (Fig. 14) to enable better consolidation of shotcrete within the space behind the chair. It is not recommended to use commonly used cast-in-place-concrete plastic chairs, as these types of chairs can create a shadow zone behind the plastic chair that is difficult to fully encase with shotcrete.

Fig. 13: A close-up view of the reinforcing steel for a 1.3 m thick wall without any multiple bundles/lap splices in both the front and back mats of rebar.

Fig. 14: Metal chairs to ensure cover is achieved. The chairs are specifically designed for shotcrete, enabling complete "wrap" of the chair with shotcrete.

"HYBRID" SHOTCRETE PROCESS

The "hybrid" shotcrete process uses bench shooting at high impact velocity, followed by supplementary consolidation by insertion of long stiff rod vibrators. Due to the thickness of these walls and the level of rebar congestion encountered, shotcrete that doesn't consolidate fully, is dealt with by "supplementary" consolidation using long rigid rod vibrators following the shooting. This process enabled full consolidation of shotcrete around rebar, embedments, and to the outer waterproofing membrane of the work. Fig. 15 shows a view of a shotcreter bench shooting the 1.3 m thick wall (background) and an operator with a long stiff rod vibrator (foreground) inserted into the work to provide supplementary consolidation of shotcrete around the back rebar and to the membrane.

Fig. 15: Shotcreter bench shooting (background) followed by an operator with a long stiff rod vibrator (foreground) being inserted into the work to provide the shotcrete with supplementary consolidation around the back reinforcing steel.

CONSTRUCTION CHALLENGES

Construction began following the first wave of COVID-19, continued during the Delta Variant wave, and ended at the onset of the Omicron variant wave. Not to overstate the fact, but this posed many challenges to CTS to stay on schedule while keeping all people safe. Very strict safety protocols were implemented onsite by CTS including the following:

a) All CTS and subcontractor employees were required to self-declare COVID-19 status before entering the site.
b) Testing was offered onsite to screen the workforce prior to shift starts.
c) All touched surfaces were wiped down with disinfectant several times a day, including surfaces in construction equipment, stair railings, and on-site trailers including lunchrooms, desks, and corridors.
d) Wash stations were set up at various quarters of the site mainly adjacent to washrooms.
e) Social distancing and mask policies were strictly enforced, as appropriate, particularly when in close quarters.

CTS implemented these costly safety protocols. There were zero shotcrete shoots cancelled due to COVID-19 infection; however, there was a period where supply of slag cement was scarce due to supply chain constraints when steel production stopped at the start of the pandemic. This situation halted the construction of the station walls for about 2 weeks until enough slag cement was available and supply chains could recover.

As this type of work was new to Toronto, Canada, CTS hired a senior shotcrete inspector from Calgary (lead author, Shaun Radomski) to spend 60 days in Toronto ensuring the work started up satisfactorily while continually monitoring the development and growth of several local shotcrete inspectors from Toronto. The local inspectors worked closely with Radomski, and then continued monitoring the work afterwards.

To achieve shoot volumes up to 224 m^3 per day, the shotcrete contractor doubled up on pumps, equipment, and crews by having two shotcreters shoot simultaneously. On the largest shoot volumes, days were long and required staging shotcreters and laborers in shifts. For instance, upwards of 6 to 8 qualified shotcreters were scheduled to share the workload in an effort to avoid burnout by rotating each shotcreter in approximately 30-minute shooting shifts. Two sets of laborers plus finishers were staggered to arrive onsite. During such days, up to three shotcrete inspectors were assigned to monitor and inspect the work on a full-time basis. This involved two inspectors starting the day, each inspector monitoring the work of one set of shotcreters, crew, and equipment. If required in the early evening hours, a third inspector would arrive and monitor shooting the remainder of the work, including the final finish coat application, finishing processes, and curing of the work.

Significant runs of steel delivery lines were used to deliver concrete to the work area. Initially, rubber hoses were used to make large vertical drops, but this proved prone to blockages in the lines causing delays and lost production to clean the lines. The delivery system was reviewed by CTS and its shotcrete contractor, and they switched to steel lines. the delivery system was switched to rubber hoses only near the nozzle in the work area. Many production days after the switch the lead author, Radomski, observed no blockages had occurred in the steel lines. This resulted from the use of the 70% slag concrete mixture design that also used natural cellulose fibres. The resulting concrete mixture had excellent slump retention. The concrete had a 90 mm +/- 20 mm (3.5 in. +/- 0.75 in.) slump after 3 hours from the time of batching.

During the first few days of shotcrete production, the ambient temperature exceeded 30 °C (86 °F) and required the introduction of liquid nitrogen into the concrete mixture to reduce the mixture temperature below a 25 °C (77 °F) maximum limit and to help with slump retention and overall quality of the concrete with respect to pumpability, shootability, and consistency to properly consolidate around rebar and allowing finishing. CTS rejected truck loads when the mixture temperature as delivered would negatively impact the quality of the concrete due to excessive ambient temperatures. CTS found that using the 70% slag cement mixture with the natural cellulose fibre, while using a spray applied curing compound, the walls were essentially crack-free.

During cold weather, considerable effort was required to heat and protect the large work areas to ensure the ambient air temperature in the shotcrete work area was maintained at a minimum of 10 °C (50 °F) and substrate temperatures maintained at a minimum of 5 °C (40 °F) to start shotcrete production. Curing blankets and supplementary heat were used to ensure that the shotcreted work did not freeze during the curing period.

Occasional sags occurred during finishing. These sags were dealt with properly by cutting the perimeter of the sagged area with a trowel to produce straight edges and removing any loose shotcrete within the sagged area.

SHOTCRETE SUPPLY, PUMPING, APPLICATION, FINISHING AND CURING/PROTECTION

A total of 7187 m^3 of shotcrete was supplied to the project and routinely met the plastic shotcrete properties of 90 mm +/- 20 mm slump with a 7 to 10% plastic air content at discharge into the pump.

The 70% slag cement concrete mixture was monitored extensively for pumping, shooting, stacking, ability to wrap rebar, consolidating, finishing, and performed well. Shotcrete was pumped long distances up to 90 m (300 ft) in the station box using steel delivery lines.

The shotcreter would typically start bench shooting in the corners, working towards the middle of the wall. The shotcreter systematically inserted the nozzle through the openings in the front mat of reinforcing steel to enable shotcrete to flow past the back mat of reinforcing steel and hit the outer waterproofing membrane with a high impacting velocity. The shotcreter achieved this by shooting at a pump stroke rate of about 20 pump strokes per minute (and sometimes higher).

Using the pipe extension, with the rubber nozzle tip wrapped tight with duct tape, enabled the shotcrete contractor to bench shoot well past the front mat of rebar (thus reducing shooting distance) and achieve a very concentrated shotcrete stream (i.e. no dispersion of the shotcrete material stream). The shotcrete placement produced a loud "rifling" type of action when hitting the receiving surface. The shotcreter would sometimes observe that the duct tape would wear out and would immediately stop the work and re-wrap the rubber tip with fresh duct tape. When the duct tape wore out, the rubber tip would tend to bulge resulting in a "fanning" out of the shotcrete stream. This reduced the impact velocity at the receiving surface and increased the build-up of fresh shotcrete on the front face of the back rebar. This was undesirable shotcrete placement and to be avoided when constructing this complex work.

A blow pipe operator worked in tandem with the shotcreter, removing any build-up of rebound from the shotcrete placement, as well as any overspray or excessive shotcrete build-up on the rebar in the area about to be shot. Behind the shotcreter, an additional blow pipe operator removed any build-up of shotcrete from the front face of the reinforcing steel, cleaned overspray from the reinforcing steel, and removed rebound. Behind the shotcreter and blow-pipe operators, an operator of a long 40 mm diameter stiff rod vibrator would systematically insert the vibrator through the front mat of rebar right to the back of the wall to provide supplementary consolidation of the shotcrete to fully encapsulate the reinforcing steel. Shotcrete inspectors hired by CTS to provide full-time monitoring of the work had a "birds-eye" view of the work in progress. They provided the shotcrete contractor with approval to proceed with the next lift of shotcrete when satisfactory shotcrete consolidation and rebar and embedments encapsulation had been achieved.

The shotcreted mixture had excellent adhesion and cohesion properties and did not slough or sag during bench shooting or when vibrated with up to 110 mm (4.5 in.) slump. This was particularly true during warm weather. At times during cold weather, slumps were reduced to a maximum of 90 mm; otherwise, some sloughing was observed in walls with less reinforcing steel congestion. Shotcrete was observed to flow beautifully around the rebar during bench shooting with the 70% slag cement mixture with the cellulose natural microfibre. Upon insertion of the long vibrator, the concrete was observed to "swim" around the most heavily congested areas and behind the back row of rebar to the waterproofing membrane, providing full consolidation.

Slump was reduced to a maximum of 80 mm when shooting the final finish coat. Finishers would cut, float, and trowel the finish coat, and no tears or pulls would occur (Fig. 16). This phenomenon was a result of using the natural cellulose microfibre in the mix, which acted as a finishing aid. Shooting the final finish coat using a wetter slump, and in areas of thicker cover, occasionally resulted in isolated sagging during cutting.

Fig. 16: Final finished surface at the West Headwall tunnel openings. Credit: Jimmy Wang.

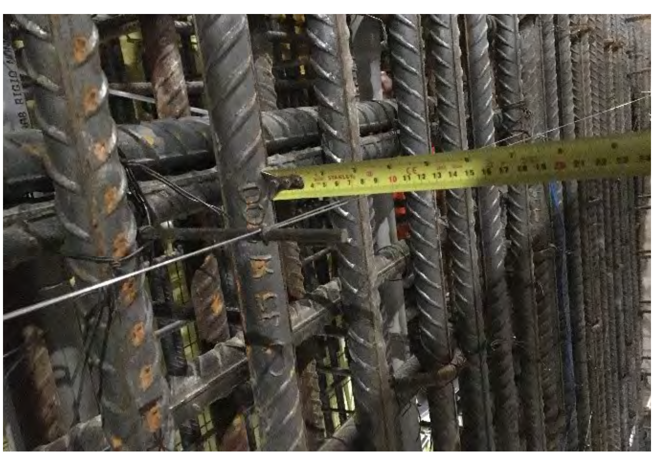

Fig. 17: Shotcrete inspector measuring the concrete cover between the front mat of rebar and the shooting wires which are stretched taut and define cover and line and finishing grade.

WR Meadows curing compound (specifically designed for vertical surfaces) was applied using a Chapin applicator. No continuous moist curing was used on this project as the natural cellulose fibre acted as an internal curing aid. Walls were found to be essentially crack-free. The occasional crack occurred when heating and protection during cold weather was required.

CONTRACTOR QUALITY CONTROL: CONSTRUCTION MONITORING AND INSPECTIONS

Construction monitoring was completed by qualified shotcrete inspectors on a full-time basis during construction of the heavily reinforced, up to 1.5 m thick, station walls. It is the opinion of the authors of this paper that full-time monitoring and inspection by qualified third-party shotcrete inspectors is critical for such work to provide assurance to the contractor and owner that the work is being done correctly, and is, therefore, strongly encouraged to be incorporated into the contractor's construction quality plan. On this project, shotcrete inspectors fill out a detailed shotcrete inspection checklist report and "signed off" on the adequacy of the work completed after each section of wall was constructed. In the checklist report, inspectors would review the following:

1. That the wall is properly prepared in advance of shotcrete application, including making the following assurances:
    a) Formwork was fully secured to prevent movement/vibration during shooting
    b) Area to be shotcreted was free of debris, rebound, or overspray
    c) Reinforcing steel was tied and secured to prevent movement/vibration during shooting
    d) Reinforcing steel was tied to avoid multiple bundles/laps/splices
    e) Bundles of excessive tie-wire were avoided
    f) Chairs were installed to provide specified shotcrete cover to the waterproofing membrane
    g) Shooting wires were installed to provide specified line and grade for finishing
    h) Cover between outer reinforcing steel, embedments, and shooting wires met specifications
    i) Scaffolding installed as needed to provide nozzlemen and finishers clear and safe access to the work
    j) Scaffolding had the required, erection safety tags

    Inspectors worked closely with the CTS quality team and a final check of the wall was completed early in the morning on each day of shotcrete application (Fig. 17).

2. First thing in the morning on the day of shotcrete placement, the shotcrete contractor's equipment approved in

the preconstruction mockup qualification, was checked for proper maintenance and operation using the following, required safety checks:

a. Pump name, model, and capacity
b. Pump hopper, grates, and discharge connections were clean
c. Checked shotcrete delivery hose pressure rating and checked for hose wear, including elbows, couplings, and seals
d. Checked that safety pins were in place at delivery hose couplings
e. Air compressor name, model, and flow rating, and checked that oil/water traps were in place
f. Air hose diameter and pressure rating
g. Checked air hose couplings for wear and that whip checks were in place
h. Shotcrete nozzle name and model
i. Checked air ring for blockages
j. Stiff immersion vibrator supplied for supplemental shotcrete consolidation
k. Vibrator had the required capacity to fully consoli date shotcrete
l. Blow pipes were provided for removal of rebound and build-up of overspray

3. Concrete ready-mix supply:
   a. Ensured the delivered concrete mixture was correct and was the same as what was approved during the mock-up
   b. Mixture was being supplied at the specified temperature
   c. Mixture was being supplied at the specified slump and plastic air content based on results of QC testing
   d. Observed pumpability and shootability, and that there was no sloughing or sagging after shooting.

4. Shotcrete application, finishing, and curing:
   a. Shotcrete hoses were properly primed prior to introducing concrete from the pump into hoses
   b. Shotcreter used bench shooting in accordance with established shooting principles (Fig. 18)
   c. Shotcrete was applied at a suitable distance from the receiving surface to achieve full consolidation around reinforcing steel and embedments (Fig. 19)
   d. Shotcrete was applied at right angles to the work (Fig. 19)
   e. Shotcreter shot benches at heights and sequences such that shotcrete did not sag or slough
   f. Bench gunned shotcrete applied to just cover outer layer of reinforcing steel
   g. Supplemental shotcrete consolidation provided for each lift of bench gunned shotcrete by systematic insertion of stiff immersion vibrator (Fig. 20)
   h. Rebound and excess overspray removed from working area with blowpipe prior to shooting
   i. Bench gunned and vibrated shotcrete was visually free of voids/sags/tears
   j. Finish coat of shotcrete was applied from top down after initial bench gunned lifts had stiffened sufficiently
   k. Air stream trickle was maintained in nozzle when not shooting to prevent blockage in air ring
   l. Finish coat shot, cut, and finished to specified line and grade to shooting wires
   m. Specified final finish was provided using floats and trowels
   n. Finished surface was free of voids, sags, tears, or plastic shrinkage cracks at time of inspection
   o. Shotcrete rebound, overspray, and cuttings/trimmings were removed from the work and disposed of in an environmentally acceptable way
   p. Shotcrete was cured to prevent from drying for at least 7 days from time of shotcrete application;
   q. Discontinued work if ambient temperature was 5°C and falling
   r. Protected shotcrete from freezing during curing period using curing blankets or heated enclosures
   s. Discontinued work if ambient temperature was 35°C and rising, if rate of evaporation exceeded 0.5 kg/sq.m./hr, and if rain was encountered during shotcrete application and finishing

Inspectors worked closely with CTS and the shotcrete subcontractor to develop solutions based on the findings from the reviews. They would stop work if necessary to address any observation deemed a quality issue, or if any of the items listed above in the inspection checklist report were checked off as a "No" during construction. From here, they would find a resolution to the deficiency and correct it; afterwards, work would continue.

Fig. 18: Inspectors would be up close and provided with a "birds eye" view of shotcrete being applied by the prequalified ACI-certified nozzleman. Shotcreter bench shooting to the back of the work.

Fig. 19: Inspectors inside the wall observing nozzleman inserting the nozzle with the pipe extension through the opening in the front mat of steel to reduce the shooting distance to the back of the work.

Fig. 20: Inspectors inside the wall observing operator inserting a long stiff rod vibrator right to the back of the work to provide the shotcrete in place with supplementary consolidation.

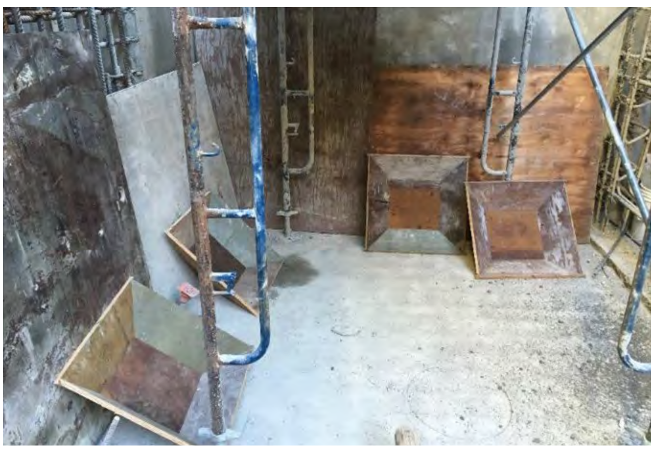

Fig. 21: Production test panels ready to be shot for taking cores and evaluating compressive strength of the concrete material at 7, 14, 28 and 56 days.

PRODUCTION TESTING

Tests were conducted to record the ambient temperature, as-batched and as-shot shotcrete temperatures, as-batched and as-shot slumps, and as-batched and as-shot plastic air contents. Tests were completed on a full-time basis for every truck load prior to discharge into the pump.

If the specified plastic shotcrete properties were not met, CTS rejected the load as part of the quality control plan. The mix used was found to have excellent slump retention due to the use of 70% slag, and no hydration stabilizer was used. Shotcrete inspectors observed that most loads would maintain slump for in excess of 3 hours, and this was plenty of time to complete full discharge of 8 m^3 size loads of shotcrete into the pump. Very rarely would a load be rejected for out-of-specification slump.

CTS shot one set of production test panels for every 40 m^3 of shotcrete placed, or one per day, whichever occurred more frequently (Fig. 21). Cores were extracted from these test panels to determine compressive strength at 7, 14, 28, and 56 days. Compressive strength test results for production days where the volume placed was a minimum of 100 m^3 are provided in Table 1.

CTS completed rigorous monitoring of temperature as part of the thermal control plan it developed for construction of the station walls. Ambient temperatures were recorded at the time of sampling the concrete by the testing technician. In addition, temperature sensors connected to sophisticated data loggers were placed in the shotcrete work area. Additional sensors (thermocouples) were placed inside the rebar cage in at least three locations along the length of the wall, and at each location, a sensor would be placed in the center, near the back, and near the front face of the wall.

These sensors recorded the temperature rise in the core of the mass shotcrete wall and at the near surfaces to determine temperature differentials between the core and the near surface of the mass shotcrete walls. Temperature monitoring continued for at least 7 days and enabled the contractor to confirm the efficacy of the thermal control plan, to confirm the timing of removal of thermal blankets during winter months, and to make any modifications required depending on the climatic conditions encountered on site. It was critical for the contractor to conduct thermal monitoring to verify that the temperature rise due to heat of hydration did not exceed 70 °C (158 °F) in the wall to prevent the potential for delayed ettringite formation (DEF). The high-volume slag cement mixture essentially eliminated any possibility of DEF unless temperatures were in excess of 85 °C (185 °F) (Ref. 8) and temperature differentials between the core of the wall and the near surface did not exceed 20 °C (70 °F) to reduce the risk of thermal induced cracking at the surface (Ref. 4). Temperature monitoring results of core temperatures and differential temperatures of production days, where the volume placed was at least 100 m^3 (130 yd^3) is provided in Table 2.

COMPRESSIVE STRENGTH TEST RESULTS

Compressive strength data is shown in Table 1 of days where production volumes achieved 100 m^3 or greater for the day. Compressive strength tested at 7 days ranged between 10.6 and 32.6 MPa (1540 and 4730 psi) and averaged 23.6 MPa (3420 psi). Compressive strength tested at 28 days ranged between 29.8 and 47.0 MPa (4320 and 6820 psi) and averaged 39.0 MPa (5660 psi). Compressive strength tested at 56 days ranged between 35.1 and 51.1 MPa (5090 and 7410 psi) and averaged 44.0 MPa (6380 psi). As shown in Table 1, the 56-day compressive strength test results typically well exceeded the specified minimum compressive strength requirement of 35 MPa (5100 psi) at 56 days.

Table 1. Compressive strength results

Mount Pleasant Station					
Average Compressive Strength (MPa)					
Location	Shoot Volume	Date Shot	Age (Days)		
	m^3		7	28	56
Secondary Entrance, West Wall, Lower Level	107	5-Aug-20	21.3	33.3	36.0
Secondary Entrance, East Wall, Lower Level	117	7-Aug-20	19.7	29.8	35.1
Secondary Entrance, West Wall, LCL	115	21-Sep-20	17.6	32.1	36.8
Station Box 1, West Headwall, Invert Level	100	20-Oct-20	10.6	34.1	41.3
Station Box 1, South Wall, Invert Level	208	5-Nov-20	24.5	37.2	42.3
Station Box 4, North Wall, Invert Level	150	12-Nov-20	21.3	37.7	39.4
Station Box 4, South Wall, Invert Level	150	19-Nov-20	18.3	36.4	-
Station Box 3, North Wall, Invert Level	216	15-Dec-20	13.3	39.3	42.7
Station Box 3, South Wall, Invert Level	216	18-Dec-20	28.5	44.8	46.5
Station Box 2, Invert South Wall	208	25-Jan-21	23.6	39.5	44.0
Station Box 2, Invert North Wall	192	3-Feb-21	26.4	41.0	43.5
Station Box 5, Headwall, Invert Level	104	5-Mar-21	26.1	40.0	46.1
Station Box 1, North Wall, UCL	224	8-Mar-21	27.0	40.2	44.5
Station Box 1, South Wall, UCL	224	10-Mar-21	26.6	39.5	46.6
Station Box 4, North Wall, LCL to UCL	184	12-Mar-21	26.0	36.3	45.4
Station Box 5, South Wall, Invert Level	184	15-Mar-21	26.8	38.2	45.3
Station Box 4, South Wall, LCL to UCL	160	24-Mar-21	25.2	41.1	43.6
Station Box 5, North Wall, Invert Level	160	30-Mar-21	24.2	42.2	45.9
Station Box 2, South Wall, LCL to UCL	160	7-Apr-21	25.3	39.2	45.7
Station Box 3, North Wall, LCL to UCL	170	14-Apr-21	25.9	40.2	44.8
Station Box 2, LCL, North Wall_East and West Segments	144	21-Apr-21	32.6	47.0	51.1
Station Box 3, South Wall, LCL to UCL	170	23-Apr-21	26.2	40.1	46.4
Station Box 4, North Wall, Roof	152	4-May-21	-	40.0	45.2
Main Entrance, Box 2, LCL, East and West Walls	100	7-May-21	22.9	39.9	45.7
Station Box 1, North Wall, UCL to Roof	144	21-May-21	24.4	39.0	45.1
Station Box 4, South Wall, UCL to Roof	112	26-May-21	22.8	41.0	45.5
Station Box 1, South and Headwall, UCL to Roof	208	28-May-21	-	40.1	45.1
Station Box 5, North Wall, LCL to UCL	100	14-Jun-21	27.2	38.4	45.4
Station Box 5, South Wall, LCL to UCL	160	16-Jun-21	23.4	37.6	41.4
Station Box 5, Headwall, LCL to UCL	160	2-Jul-21	26.1	40.9	45.1
Station Box 2, North East and North West Walls, UCL	120	20-Jul-21	22.8	39.8	44.8
Station Box 2, South Wall, UCL to Roof	180	26-Jul-21	24.9	40.6	45.2
Main entrance East and West Walls	100	5-Aug-21	22.8	39.6	44.8
Secondary Entrance (Station Box 5), West Wall, UCL	140	6-Aug-21	22.3	39.4	43.2
Station Box 5, Headwall, Roof and Secondary Entrance	120	12-Aug-21	22.1	39.0	43.2
Station Box 5, South Wall, UCL to Roof	120	20-Aug-21	22.1	38.7	44.2
Station Box 3, North Wall, UCL to Roof	115	27-Aug-21	26.5	39.9	45.4
Main entrance, East, West, North U-Shaped Walls, UCL	112	3-Sep-21	23.1	38.8	44.6
Total Shotcrete Volume	**7187**				
	Mean		**23.6**	**39.0**	**44.0**
	StDev		**4.1**	**3.1**	**3.1**
	Specs		**-**	**-**	**Min 35**

Table 1. Compressive strength results

THERMAL MONITORING RESULTS

Thermal monitoring data is shown in Table 2 of days where production volumes achieved 100 m^3 or greater for the day to build the wall location indicated at Mount Pleasant Station. Thermal monitoring data revealed that the mean temperature rise in the core was 55.9 °C (101 °F) and individual test results (with one exception) satisfied the 70°C limit. Differential temperature results averaged 13.1 °C (24 °F), and other than one outlier, they were all below 20°C. The walls presented in Table 2 ranged in thickness from 1.0 m (3.3 ft) to 1.5 m (Figs. 22-25).

Table 2. Thermal Monitoring Results

Mount Pleasant Station				
Thermal Monitoring				
Location	**Shoot Volume m^3**	**Date Shot**	**Core Temp. (°C)**	**Differential Temp. (°C)**
Secondary Entrance, West Wall, Lower Level	107	5-Aug-20	51.2	13.1
Secondary Entrance, East Wall, Lower Level	117	7-Aug-20	53.3	10.3
Secondary Entrance, West Wall, LCL	115	21-Sep-20	46.5	7.7
Station Box 1, West Headwall, Invert Level	100	20-Oct-20	43.6	6.8
Station Box 1, South Wall, Invert Level	208	5-Nov-20	52.0	7.8
Station Box 4, North Wall, Invert Level	150	12-Nov-20	50.8	12.3
Station Box 4, South Wall, Invert Level	150	19-Nov-20	47.1	11.2
Station Box 3, North Wall, Invert Level	216	15-Dec-20	54.9	12.5
Station Box 3, South Wall, Invert Level	216	18-Dec-20	54.9	12.5
Station Box 2, Invert South Wall	208	25-Jan-21	58.2	11.7
Station Box 2, Invert North Wall	192	3-Feb-21	49.5	9.4
Station Box 5, Headwall, Invert Level	104	5-Mar-21	48.4	22.7
Station Box 1, North Wall, UCL	224	8-Mar-21	57.1	13.9
Station Box 1, South Wall, UCL	224	10-Mar-21	61.4	11.8
Station Box 4, North Wall, LCL to UCL	184	12-Mar-21	56.5	14.9
Station Box 5, South Wall, Invert Level	184	15-Mar-21	58.5	17.6
Station Box 4, South Wall, LCL to UCL	160	24-Mar-21	62.8	16.6
Station Box 5, North Wall, Invert Level	160	30-Mar-21	60.1	18.2
Station Box 2, South Wall, LCL to UCL	160	7-Apr-21	61.2	17.6
Station Box 3, North Wall, LCL to UCL	170	14-Apr-21	51.7	13.7
Station Box 2, LCL, North Wall_East and West Segments	144	21-Apr-21	57.1	13.9
Station Box 3, South Wall, LCL to UCL	170	23-Apr-21	54.7	13.5
Station Box 4, North Wall, Roof	152	4-May-21	51.1	7.8
Main Entrance, Box 2, LCL, East and West Walls	100	7-May-21	46.0	5.6
Station Box 1, North Wall, UCL to Roof	144	21-May-21	56.8	12.1
Station Box 4, South Wall, UCL to Roof	112	26-May-21	59.4	16.1
Station Box 1, South and Headwall, UCL to Roof	208	28-May-21	48.4	5.4
Station Box 5, North Wall, LCL to UCL	100	14-Jun-21	58.7	18.0
Station Box 5, South Wall, LCL to UCL	160	16-Jun-21	55.3	17.9
Station Box 5, Headwall, LCL to UCL	160	2-Jul-21	59.4	16.5
Station Box 2, North East and North West Walls, UCL	120	20-Jul-21	58.7	11.3
Station Box 2, South Wall, UCL to Roof	180	26-Jul-21	57.8	13.8
Main entrance East and West Walls	100	5-Aug-21	58.6	10.1
Secondary Entrance (Station Box 5), West Wall, UCL	140	6-Aug-21	61.7	13.5
Station Box 5, Headwall, Roof and Secondary Entrance	120	12-Aug-21	72.2	13.0
Station Box 5, South Wall, UCL to Roof	120	20-Aug-21	61.2	15.5
Station Box 3, North Wall, UCL to Roof	115	27-Aug-21	66.6	18.6
Main entrance, East, West, North U-Shaped Walls, UCL	112	3-Sep-21	62.6	14.3
Total Shotcrete Volume	**7187**			
		Mean	**55.9**	**13.1**
		StDev	**6.1**	**3.9**
		CSA A23.1	**Max. 70°C**	**Max. 20°C**

Table 2. Thermal Monitoring Results

EXAMPLES OF PARTIALLY CONSTRUCTED AND COMPLETED STRUCTURAL SHOTCRETE WALLS

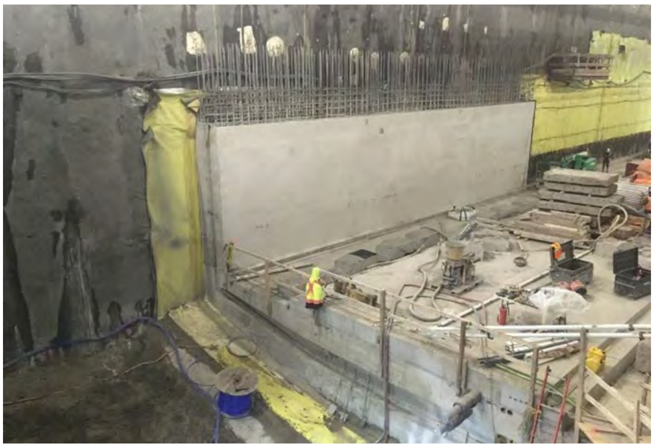

Fig. 22: Mount Pleasant Station, Box 4, South wall, invert slab level, 1.3 m thick.

Fig. 23: Mount Pleasant Station, and a close-up view of the tunnel arch that was constructed using the "hybrid" shoot and then vibrate shotcrete process for the West headwall.

Fig. 24: Mount Pleasant Station, and an example of the excellent shotcrete quality demonstrated upon stripping the bulkhead form at the embedded plastic waterstop.

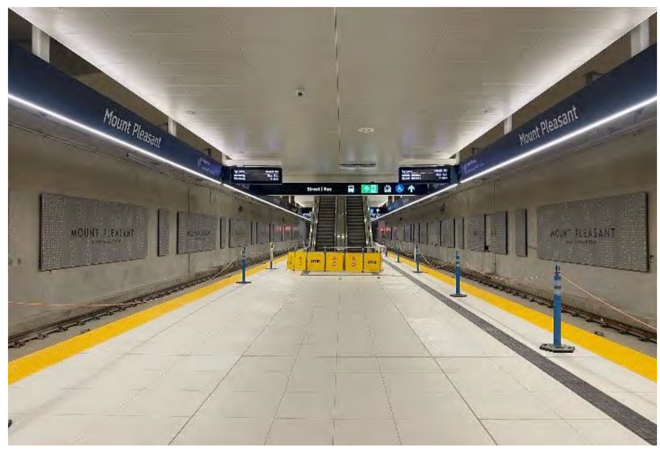

Fig. 25: Finished Mount Pleasant Station.

CONCLUSIONS

This paper demonstrates that a successful execution of the "hybrid" shoot and vibrate shotcrete process to construct up to 1.5 m thick, heavily reinforced with up to four layers of #35M (#11) rebar for underground mass shotcrete station walls requires the following:

1) A comprehensive preconstruction mockup construction, which includes the prequalification of the following:
   a) Concrete mixture design
   b) Shotcrete equipment
   c) Shotcrete shotcreter, including these:
      i) Understanding of optimizing pump pressure and shooting distance to achieve a high impacting velocity using standard bench shooting techniques
      ii) Blow piping
      iii) Vibrating
      iv) ACI shotcrete shotcreter certification

2) Use of the same equipment, the same prequalified shotcreter, and the same mixture design during construction once satisfactory mockup results are achieved, including evaluation of the following:
   a) Wire saw cuts and quality of shotcrete around reinforcing steel and embedments, and to the back waterproofing membrane
   b) Compressive strength
   c) Thermal properties

3) During construction, adoption of a rigorous quality control inspection and testing plan, which includes completing the following:
   a) Full-time inspection and monitoring by qualified, third-party shotcrete inspectors
   b) Full-time testing of each ready-mix concrete truck, including measurement of temperature, slump, and plastic air contents
   c) Compressive strength testing of cores at a specified frequency
   d) Temperature monitoring of the mass shotcrete structure to ensure temperature limits not exceeded

In summary, the total volume of shotcrete placed at Mount Pleasant Station was 7,187 m^3. The concrete mixture design routinely met the specified compressive strength and thermal requirements. The work was monitored and inspected on a full-time basis. The slag cement concrete mixture was pumped, shootable, and stackable. Proper consistency of the concrete allowed excellent encasement of the rebar and embedments. Additionally, 10 pre-qualified nozzlemen demonstrated proper "hybrid" shoot and vibrate placement and consolidation techniques.

This project has demonstrated a growth in knowledge and acceptance in the Toronto construction industry to use shotcrete to construct thick, up to 1.5 m, heavily reinforced metro or LRT underground station structural walls using the "hybrid" (shoot and vibrate) shotcrete construction method. It also showed that lower carbon concrete using a high volume of slag cement (up to 70% replacement of portland cement with slag) provided quality shotcrete placement, with the desired thermal and hardened properties (Ref. 3). The success of the method relies on these factors:

- Ready-mix concrete suppliers able to provide suitable shotcrete mixtures
- Experienced shotcrete contractors, including ACI-certified nozzlemen and crew, able to provide high-quality constructed structures
- Shotcrete inspectors with knowledge and experience to monitor the shotcrete work and sign off on the acceptability of the completed work.

Due to the technical and economic success of the system the same approach has now been used to construct other station walls at Leaside, Cedarvale, Forest Hill, and Yonge Stations along the Eglinton Crosstown LRT line to the satisfaction of the contractor and owner. In addition, another LRT Line in Toronto is using the same system at new two station projects.

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8. CSA A23.1-19, Annex T

ACKNOWLEDGEMENTS

Owner
Metrolinx and Infrastructures Ontario

General Construction Contractor and Designers:
Crosslinx Transit Solutions, a general partnership comprised of SNC-Lavalin Constructors (Pacific) Inc., Dragados Canada Inc., EllisDon Civil Ltd., and Aecon Infrastructure Management Inc.

Construction Project Managers, **Eduardo Hernandez Arnanz, Mario Prieto Dominguez, Laura Di Monte**

Construction Quality Lead, **Bashir Alim**

Design Engineer, **Ken Stranks**

Shotcrete Contractor, **Torrent Shotcrete**

Shotcrete Pump Equipment, **Reed**

Shotcrete Ready-Mix Supplier, **Innocon, CBM**

Shotcrete Testing Company, **Qualitylinx**

Shotcrete Construction Inspectors, **WSP E&I Canada Ltd.**

Project Consultant and Senior Shotcrete Inspector, **Shaun Radomski**

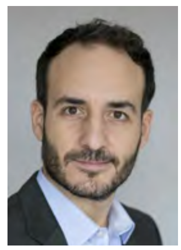
Resident Shotcrete Inspectors, **Jimmy Wang, Robert Mattes, Leonard Crasta, Graeme Lowry**

Technical Support, **Dr. Rusty Morgan, Dr. John Zhang**

Shaun M. Radomski *is a Civil Materials Engineer specializing in concrete and shotcrete technology and the evaluation and rehabilitation of infrastructure. He has over 17 years of civil materials engineering, inspection, and testing experience in Canada and the United States. He is a member of ACI Committees 506, Shotcreting; and C661 Shotcrete Inspector Certification. Based in Calgary, AB., Mr. Radomski has extensive shotcrete consulting, inspection, and testing experience across North America, all with WSP and its predecessor companies. He has experience with both wet-mix and dry-mix shotcrete in a variety of applications and with many sophisticated concrete mixtures Radomski received a MSc in Civil Engineering from Ryerson University, Toronto, ON, Canada, where he conducted research on using SCM's to enhance the durability of concrete against sulphate attack and alkali aggregate reactivity.*

Dudley R. (Rusty) Morgan, Ph.D., F.ACI, *is a Civil Engineer with over 50 years of experience in the concrete and shotcrete industries. He served as a member and Secretary of ACI Committee 506, Shotcreting, for over 25 years. He is a past member of ACI Committees 365, Service Life Prediction, and 544, Fiber-Reinforced Concrete. Morgan is a founding member and Past President of ASA. He is an ASA/ACI C660-approved Shotcrete Nozzleman Examiner. Morgan is a past member of the Canadian Standards Association Concrete Steering Committee and was a Canadian Representative on the International Tunneling and Underground Space Association Committee, Shotcrete Use. He has worked on over 1000 concrete and shotcrete projects around the world during his consulting career and has edited five books and published over 150 papers on various aspects of concrete and shotcrete technology. In 2001, Morgan was elected as a Fellow of the Canadian Academy of Engineering.*

Lloyd Keller, F.ACI, *is the founder of Research and Development and Quality Control for EllisDon Construction in Mississauga, Ontario. He is fellow of ACI and participates in numerous committees for ACI and CSA in Canada. He was educated at BCIT in Canada specializing in Civil and Structural Engineering Technology. His research efforts have been focused, over the last number of years, on Self Consolidation Concrete (ACI Committee 237) and the prediction of formwork pressure. Shotcrete for structural installations and the control of exothermic heat generation with the utilization of high-volume supplementary cementing materials is also an area of research over the last few years.*



Daniel Sanchez *is a Professional Engineer with over two decades' background in the heavy civil infrastructure construction industry. Highly experienced in the lifecycle of the project from conceptual design through development and delivery, he has participated in numerous underground projects in Spain and Canada, including Metro Line 9 of Barcelona, the Eglinton Crosstown LRT of Toronto or the Scarborough Subway Extension. Daniel holds a master's degree in civil engineering by the University of Granada, Spain.*

Laura Di Monte *is a mechanical engineer with Bell in Toronto, Canada. She worked as the Technical Project Coordinator for the Mount Pleasant Station project.*

Rosemary Esposito, Patriot Shotcrete

Nominated by Frank Townsend

Rosemary was new to the industry three years ago; she is the widow of one of our operators, Joe Esposito, who was a loyal, excellent operator.

Rosemary is extremely dedicated and hardworking. She is far beyond extremely organized and is focused on continuously learning and developing best practices to manage routine activities both efficiently and effectively, from working with unions, to insurance, to accounts payable, accounts receivable, and beyond. Rosemary has a positive aura and high energy with her personal touch.

Over the past three years, she has developed processes and procedures for managing our department that have thoroughly impressed me. This brings consistency and helps each of us, from the office to the field, with tasks from daily activities to audits.

She genuinely cares about delivering excellent, quality work. She strives to integrate both an understanding of the big picture strategy and goals, as well as attention to details. Many times, over the last few years, I have approached her on a non-standard matter with only a vague idea in my mind of what we needed or wanted to do. She always takes the initiative to figure out what the issue needs with minimal guidance from me, and then delivers on the task.

Pictured Left to Right: George Machikas, Rosemary Esposito, and Frank Townsend of Patriot Shotcrete at the Surf for Autism event on Long Island, NY sponsored annually by Patriot.

Rosemary always goes above and beyond the call of duty in pursuing excellence. She is integral to the Patriot team and to our continued success.

The American Shotcrete Association congratulates Rosemary Esposito on being nominated for Shotcreter Spotlight: Women in Shotcrete and for her outstanding commitment to her work at Patriot Shotcrete.

NEW ASA MEMBERS

SUSTAINING CORPORATE MEMBER

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www.artisanskateparks.com
Primary Contact: Andy Duck
artisanandy66@gmail.com

Ocean Rock Art Ltd.
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SUSTAINING CORPORATE COMPANY

Artisan Pools NC, Inc.
Kitty Hawk, NC

Ocean Rock Art US LLC
Kitty Hawk, NC

CORPORATE

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Jensen's Concrete Pumping and Pressure Grouting Services
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www.pressuregrouting.us
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Jeff Sheiber
COST of Wisconsin Inc
Orlando, FL

INTERESTED IN BECOMING A MEMBER OF ASA?

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

MASTER BUILDERS' RHEOLOGY CONDITIONER EASES TYPE IL CONCRETE MIX WORK

World of Concrete 2024 marked the formal North American market debut of Master Builders Solutions' MasterEase, a next generation rheology-modifying, water-reducing admixture. Recently developed polymers enable the new ASTM C494 Type A agent to lower concrete viscosity compared to prior water reducing admixtures. The polymers reduce yield stress, the main indicator of concrete flow properties, making MasterEase especially suited to mixes designed with a) ASTM C595 Type IL portland limestone cements or supplementary cementitious materials (SCMs); and b) coarse, manufactured sands or marginal virgin or recycled aggregates that exhibit angular shapes or other properties that quality control professionals tend to avoid using.

As cement producers migrate from ASTM C150 Type I/II to C595 Type IL, Master Builders Solutions officials note that concrete producers and their customers experience mixes with lower early-age strength development and sticky, harsh characteristics. The latter results in pumping, placing and finishing difficulties, leading to greater equipment wear and tear, plus lower crew productivity. Master Builders Solutions is promoting the new admixture for a wide range of low- to high-slump conditions. MasterEase excels in extruded mixes for curb & gutter applications and prestressed hollow core plank. The new, patent protected polymer technology was developed by Master Builders Solutions' scientists with higher sustainability applications in mind, such as enabling the use of high clinker replacements and artificial aggregates.

Fig. 1: MASTEREASE VS. PCE SUPERPLASTICIZER - L-box flowability test results show the improved placement characteristics of a MasterEase (left, six-second flow) mix versus one dosed with a polycarboxylate ether superplasticizer (right, 22-second flow). Both specimens bear the same mix designs and target slumps.

The MasterEase rollout follows widespread market uptake of Master X-Seed, a strength-enhancing admixture family that Master Builders Solutions brought to the North American market in 2018. That timing anticipated broader Type IL and SCM use in North America, especially in major construction markets — *www.master-builders-solutions.com.*

BLASTCRETE EQUIPMENT LAUNCHES X-40D SWING TUBE PISTON PUMP FOR HIGHER-VOLUME APPLICATIONS

Blastcrete Equipment LLC, a leading manufacturer of concrete pumps for the refractory, mining and construction industries, introduces the X-40D trailer-mounted concrete pump system. This compact but efficient pump provides high-volume pumping in a compact design for a variety of applications and rounds out the Blastcrete product line with a low-maintenance, versatile pump, capable of handling a range of rock sizes.

Maximum Versatility

The X-40D makes pumping concrete with a variable blend of rock simple, compared to other market options. Capable of handling aggregate mixes up to 1.5 in. (38 mm), the X-40D provides a highly versatile pump solution that contractors can use for a vast array of projects ranging from residential concrete jobs to highway infrastructure improvements.

"This unit is the culmination of an industry-oriented engineering process and supply partnership focused on increasing versatility and decreasing maintenance. Additionally, because we spent time talking with contractors in the field, we saw the importance of features like remote-control operation," said Scott Knighton, Co-CEO of Blastcrete Equipment LLC, "Although touchscreens have become common with this equipment, our design eliminates them because customer feedback indicated they are difficult to operate when wearing gloves wet with concrete. This intentional focus on the needs of the customers in our design makes the X-40D a product we are proud of and excited to bring to the industry."

The X-40D incorporates a unique PULSAR piston pump from Mecbo to deliver high volume in a compact design. The PULSAR pump incorporates a long stroke to push a greater volume of concrete with less mechanical movement, thereby reducing maintenance and providing a smooth pour. The Mecbo PULSAR pump system has also been shown to reduce energy consumption by 30 to 40%.

Less energy does not translate to less power. The 6 in. x 39 in. (150 mm x 975 mm) swing tube piston pump is complimented by a rugged receiving agitator to keep the concrete mixed and prime for pumping. The X-40D pump boasts 1,000 psi (7 MPa) of piston face pressure, with a 5 in. (125 mm) discharge and the ability to put out 40 yd^3 (31 m^3) of concrete per hour. Blastcrete engineered it for minimal maintenance to limit downtime.

"The durability of the product stands as a testament to Blastcrete's unwavering commitment to producing equipment that is reliable, made in America, and easy to use," said Knighton.

Fig. 1: Blastcrete Equipment LLC, a leading manufacturer of concrete pumps for the refractory, mining and construction industries, intro-duces the X-40D trailer-mounted concrete pump system.

Smooth Mobility

The 7,080 lb (3210 kg) pump and integrated trailer is easy to haul to jobs that range from creating piers for overpasses to backyard projects such as installing in-ground swimming pools.

The pump's four crane lifting eyes also provide significant transportation advantages, allowing operators to position the machine precisely where they need it. Forklift tubing is mounted to the lower hopper for convenient flat pack removal.

Fig. 2: The X-40D incorporates a unique PULSAR piston pump from Mecbo to deliver high volume in a compact design.

Cementing Success in the Field

The X-40D strikes the balance between modern technology and user-friendliness. Blastcrete considered customers and the environments in which they work with the design of this machine. It features a wireless remote control to provide operators the unparalleled convenience of controlling the pump's functions with precision from a distance. The durable, solid-state electronic components function in a wide variety of weather conditions.

Factory options that can be added include the Auto Lubrication System and the 12 VDC Screen Vibrator. Power options include the 72-horsepower Yanmar 4TNV98CT-NKW diesel, a 74-horsepower Deutz TD2.9 diesel or a 75-horsepower electric motor. Both diesel engines are water cooled with no diesel exhaust fluid.

Fig. 3: The X-40D pump boasts 1,000 psi of piston face pressure, with a 5-inch discharge and the ability to put out 40 cubic yards of concrete per hour. Blastcrete engineered it for minimal maintenance to limit downtime.

Like all Blastcrete products, the X-40D is backed by a dedicated team of industry experts for outstanding customer service. Blastcrete technicians are available online and by phone for equipment questions, troubleshooting and replacement parts. They also offer free customer product training. Contact them at 1-800-235-4867 or visit www.blastcrete.com.

About Blastcrete Equipment LLC

Blastcrete Equipment LLC has been manufacturing safe, reliable and user-friendly solutions for the refractory and shotcrete industries for more than 70 years. With a complete product line consisting of concrete mixers, pumps and related products, the company serves the commercial and residential construction, ICF building systems, refractory and underground markets. For more information: Blastcrete Equipment, LLC 2000 Cobb Ave., Anniston, AL, 36202; 800-235-4867; fax 256-236-9824; 1-256-235-2700 (International); info@blastcrete.com; www.blastcrete.com; LinkedIn; Facebook; YouTube.

Fig. 4: Blastcrete considered customers and the environments in which they work with the design of this machine. It features a wireless remote control to provide operators the unparalleled convenience of controlling the pump's functions with precision from a distance.

Women in Shotcrete 2025!

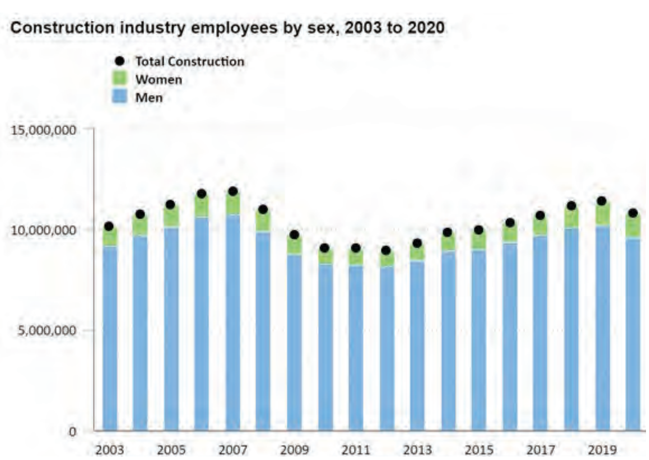
By Alice McComas, Senior Editor

It's no secret that the construction industry is male-dominated. There is a wealth of statistical data that documents this workforce gap. But women have been and continue to be valuable participants in the concrete construction world. Many groups have formed to bring the value and impact of women to the forefront of our industry. As ASA advances acceptance of shotcrete placement, we must also play a role in bolstering efforts to increase recognition and participation of women in our industry.

NAWIC (The National Association of Women in Construction) reports that: *Women in the U.S. earn on average 82.9 percent of what men make. The gender pay gap is significantly smaller in construction occupations, with women earning on average 95.5 percent of what men make.* (www.bls.gov/opub/reports/womens-databook/2021/home.htm, Table 19)

A 2023 report from the Bureau of Labor Statistics (BLS) reveals that 10.8% of construction workers in the United States are women. Women in construction only make up 1.25% of the total US workforce, despite constituting 47% of all employed individuals. (www.bls.gov/cps/cpsaat18.htm)

OSHA (Occupational Safety and Health Administration) reports: *In 2020, women accounted for 1.2 million of those employed in the construction industry, or about 1 in 10, similar to recent years.* (US Bureau of Labor. 2022. Publications, Spotlights on Statistics, Construction Industry Employees by Sex, 2003-2020, 1 in 10 Construction Workers is A Woman.)



Source: U.S. Bureau of Labor Statistics (https://www.bls.gov/spotlight/2022/the-construction-industry-labor-force-2003-to-2020/home.htm)

It is no surprise that many groups formed, borne out of a desire to support this underrepresented population in the construction industry. A few national, female-focused organizations of note in the construction industry include:

NAWIC (The National Association of Women in Construction) seeks to "provide its members with opportunities for professional development, education, networking, leadership training, public service and more… advocating for the value and impact of women builders, professionals and tradeswomen in all aspects of the construction industry." *nawic.org*

SWE (Society of Women Engineers) seeks to "empower women to achieve their full potential in careers as engineers and leaders; expand the image of the engineering and technology professions as a positive force in improving the quality of life and demonstrate the value of diversity and inclusion." *swe.org*

WIRE (Women in Restoration & Engineering)'s "mission is encouraging and empowering women in the restoration, engineering, design, construction, management, ownership, material support, conservation, environmental or any field relevant to the Built World!" *womenwire.org*

Closer to ASA's circle of associations we also see a nod to this need. Both ACI (American Concrete Institute) and ICRI (International Concrete Repair Institute) have committees for Women in ACI & Women in ICRI. Both are established groups within their organizations and enjoy a vibrant community.

Why is this important? It is largely the same need we all have. In our community, we learn from and with each other. In our community, we grow and support each other. In our community, we step outside ourselves and find ourselves. Connecting with others with like issues or seasons in their careers (peer-to-peer), with those who are a bit more seasoned and experienced (mentee-to-mentor), or with those who are less experienced or newer to their roles (mentor-to-mentee) – all contribute to our development.

Yet tangibly, there are needs as well. It's easy for these needs to be disregarded if they only represent a small portion of the population. From worksite accommodations to properly fitting PPE, there are necessities, when not addressed, hinder the success of this group. If women are to continue growing and contributing in this industry, the same rights to properly fitting PPE and safe working conditions need to apply. Intentional inclusion is important and requires a heightened awareness of what's involved.

ADDITIONAL LINKS TO RESOURCES

SWE – Fast Facts 2023

Exploring Women in Engineering Leadership: A Case Study

As a much smaller organization, ASA also recognizes the presence of this group in women-owned businesses; office support staff which, honestly, keeps the business running; engineers who are designing structures for shotcrete placement or involved in research and development, improving the materials and equipment which supports our industry; and women who are in the field shooting shotcrete! In fact, ACI has recognized this reality in their recent vote to officially change the certification program name from "shotcrete nozzleman" to "*shotcreter*." From the ACI 506 committee to the ACI C660 Shotcreter Certification program, this change will ripple through the industry as all references to *nozzlemen* will now shift to *shotcreter*!

In 2025, the theme for our 4th Quarter issue of *Shotcrete* magazine will be Women in Shotcrete! If you are a woman in the shotcrete industry, we want to feature you! Please take a moment to complete this short survey which will inform a feature in that issue: *Faces of Women in Shotcrete*. Here's an opportunity to prove how large and influential a community of women we have in our industry. You never know, your story might be the inspiration in another woman's journey that could make all the difference! You have a voice and *Shotcrete* magazine would love to give you a platform to share it!

If you have questions, article ideas, or want to contribute, contact us at info@shotcrete.org. We'd love to hear about your journey and the expertise you bring to our industry.

Faces of Women in Shotcrete survey.

Fill it out today!

Crafting Experiences, Building Dreams: Cost of Wisconsin Inc.

For over six decades, Cost of Wisconsin Inc. has been a pioneering force in the themed construction industry, specializing in creating immersive environments that redefine the way we experience the world around us. Since our inception in 1957, COST has excelled in blending proven construction methodologies with an artistic flair. This practice has solidified our presence as an industry leader within zoos, aquariums, theme parks, museums, and casinos in North America and abroad. By consistently delivering excellence on every project, we constantly set new standards for innovation, craftsmanship, and execution.

EXCELLENCE THROUGH INNOVATION

The cornerstone of our success is innovation. With a passion for pushing the boundaries of what's possible, we harness the latest technologies and sustainable practices to turn ambitious concepts into reality. Through constant experimentation with materials and fabrication methods, we're always developing the next level of realism. Our skilled staff of designers, project managers, and artisans collaborate seamlessly to bring even the most imaginative visions to life.

CRAFTSMANSHIP REDEFINED

Strength, versatility, and appearance are the key ingredients in COST's shotcrete craftsmanship. The versatility of shotcrete placement is truly amazing and often the best choice in large, complex situations. Its bonding properties, structural strength, durability, finishing versatility, and ease of application allow for many creative uses. With meticulous attention to detail and an unwavering commitment to

quality, we transform ordinary spaces into extraordinary works of art. The flexibility of shotcrete placement allows us to fabricate thematic elements that seamlessly blend with their surroundings. From sculpting rock work to themed ruin walls, shotcrete allows us to create visitor experiences that leave a lasting impression.

PRECISION EXECUTION

At Cost of Wisconsin Inc., we understand that success lies in meticulous planning and flawless execution. We collaborate closely with clients, architects, and engineers to bring their visions to life. From preconstruction consultations to on-site fabrication, our team is with you every step of the way to ensure that every project is completed to the highest standards of quality and craftsmanship.

RECENT REFERENCE PROJECTS

Recent projects, such as the award-winning Gilder Center at the American Museum of Natural History, and the Fresno Chaffee Zoos Kingdoms of Asia, exemplify our commitment to excellence in blending artistic talent with shotcrete placement. These projects showcase our expertise in both shotcrete placement and theme construction by creating immersive environments that leave visitors in awe.

YOU DREAM, WE DELIVER: OUR PROMISE

At Cost of Wisconsin Inc., our motto is simple: You Dream, We Deliver. With over 67 years of experience and a track record of turning even the most ambitious ideas into reality, we have the expertise, creativity, and passion to bring your vision to life. Whatever your dream, whatever your vision, we are here to make it a reality.

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GeoStabilization International

Founded in 2002, GeoStabilization International grew from a passion to protect people from the risk of geohazards and a drive to do so with cutting-edge solutions that increase efficiency, decrease cost, and minimize environmental impact. Today, our leading mitigation firm in North America has grown to a team of more than 600 people composed of geologists, geotechnical engineers, equipment operators, geohazard mitigation technicians, data analysts, and rockfall remediation technicians.

With a primary focus on supporting geohazard mitigation in emergency response scenarios, the team is strategically decentralized across the United States and Canada – ensuring crews are available to respond within 24-48 hours. GeoStabilization's engineering and construction offerings provide seamless integration of design and construction and allow for rapid assessment and implementation of changes when unexpected subsurface conditions are encountered.

NORTH AMERICA'S LEADER IN SHOTCRETE WALL AND SCULPTED SOLUTIONS

GeoStabilization International has applied nearly 2 million ft^2 (186,000 m^2) of shotcrete on more than a thousand projects across the United States and Canada to date. By using the most advanced shotcrete and sculpted concrete technologies available, we are able to decrease environmental impact and give customers a solution that saves significant time and money. Spraying concrete onto vertical or overhead surfaces with high velocity, results in similar strength, density, and durability as traditional methods like cast-in-place but is more versatile, economical, and better suited in hard-to-access areas.

To create earth retention systems and structural support and to emulate natural-looking architecture, GeoStabilization uses sculpted concrete – a method of shaping concrete shortly after spraying it, while it is still wet and malleable. This technology is used when constructing shotcrete wall retention systems like soil nail walls, shotcrete-faced soldier pile walls, and shotcrete-faced lagging walls.

TRANSFORMING SHOTCRETE APPLICATION

In 2022, GeoStabilization developed the Shotcrete Robot[1], providing a new technology for shotcrete application by enabling technicians to spray concrete remotely rather than manually holding a shotcrete nozzle and hose. A remote allows the operator to easily see and reach hard-to-access areas and spray from a safe distance. This innovation provides countless advantages, including faster application, low environmental impact, better visibility of the shotcrete face, and overall higher-quality installations. It also enhances the safety of the technicians, crews, and anyone surrounding a jobsite.

Fig. 1: Shotcrete Robot.

FEATURED PROJECT

Fig. 2: Beginning Stabilization of SR 27.

When State Route 27 near Chattanooga, Tennessee, experienced distress due to its rocky colluvium-based geology, GeoStabilization implemented a cost-efficient solution through value engineering. Instead of constructing a traditional H-pile wall, the team opted for a soil nail wall with a stained and sculpted shotcrete finish.

Due to the site's unique geological conditions, GeoStabilization determined that drilling and grouting soil nails into the slope would be the best method for stabilization. This approach offered an economical solution without compromising performance. With a relatively quick construction process, it also helped accelerate project deadlines to minimize disruptions along the active state route.

Fig. 3: Progress Photo of Geological Facing Installation and Sculpting.

Ensuring that the structure blended in with the natural surroundings was crucial in determining the right solution. The team used a stained and sculpted shotcrete finish over the soil nail wall to resemble in situ rock formations. Their meticulous approach included studying the surrounding environment, capturing the right colors, and paying attention to minute details. With the use of aerial drone footage, they were able to match the natural geology of the area successfully.

Through its innovative techniques, environmentally conscious practices, and enhanced visual appeal, the project not only elevated industry standards but also positively impacted the client, community, and construction industry.

Fig. 4: Final Wall with Geological Facing, Facing South.

[1]https://www.geostabilization.com/techniques/technology/shotcrete-robot/

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GSI ACQUIRES ACCESS LIMITED CONSTRUCTION AND COMPLETES THE US 340 ROCKFALL MITIGATION PROJECT IN WEST VA IN RECORD TIME

In a February 2023 Press Release, GSI announced it had acquired Access Limited Construction, "the industry leader in rockfall." Access Limited Construction is based out of California, and the acquisition brings their combined expertise together to work on projects from the East Coast to the West Coast!

And that's exactly what they did when, in late 2023, Access Limited Construction, along with partner, Triton Construction Inc., a "top heavy/highway civil contractor," completed the "highly traveled US 340 in West Virginia" two weeks earlier than planned!

In December 2023, GSI noted that "Work included stabilizing the corridor through rock slope scaling, removal of rockfall hazards, and localized rock bolting. The crews also repaired pavement and guardrail that was damaged from falling rock and installed draped and pinned mesh, ground-level rockfall barriers, and on-slope rockfall attenuator systems to reduce future rockfall events and safely catch any rocks that may fall."

Congratulations to Geostabilization International, Access Limited Construction, and Triton Construction Inc., as well as their other partners, on their monumental achievement repairing a section of road that "experiences an estimated 24,500 vehicles a day" from commuters and local traffic from three states.

Visit **www.alccinc.com** and **www.geostabilization.com/** for more information.

SIKA ACQUIRES THIESSEN TEAM USA AND EXPANDS US MINING MARKET

In a July 2023 Press Release, Sika announced it acquired Thiessen Team USA, which is a leading "US manufacturer of shotcrete and grouting products for the mining industry in the USA." Thiessen was founded in 1954 as a family-owned business, and through "long-established, strong relationships with large mining customers, [it] has built a reputation for excellent quality, hands-on technical support, and fast reaction times." Thiessen currently "operates two production facilities which are strategically located close to large mines in the western US, which…excavate materials essential for the production of batteries."

Congratulations to Sika and Thiessen, both long-time, corporate and now sustaining corporate members of ASA.

For more information, visit **www.usa.sika.com/**

JEAN-CLAUDE ROUMAIN INNOVATION IN CONCRETE AWARD

An award for innovation in concrete has been established by CIC in memory of Jean-Claude Roumain, a long-time CIC supporter and Executive Committee member who passed away in January 2010.

"for your leadership in shotcrete innovation, improvements, advancements, and for striving to evaluate new technologies"

Congratulations to one of ASA's finest, Marc Jolin, FACI. Marc Jolin has been a Professor in the Department of Civil and Water Engineering at Université Laval, Québec, QC, Canada, since 2005 and is a member of the Research Centre on Concrete Infrastructures (Centre de recherche sur les infrastrucures en béton [CRIB]). He is Chair of ACI Committee C661, Shotcrete Inspector Certification, and past Chair and a member of ACI Committees 506, Shotcreting, and C660, Shotcrete Nozzleman Certification. Jolin is also an active ACI Examiner for Shotcrete Nozzleman Certification (wet- and dry-mix processes) and a member of the American Shotcrete Association (ASA). He received the ACI Young Member Award in 2009 and was nominated Fellow of the Institute the following year. He also received the 2017 ACI Certification Award and the 2021 Delmar L. Bloem Distinguished Service Award. Jolin received his bachelor's degree and MSc from Université Laval in 1994 and 1996, respectively, and his PhD in civil engineering from the University of British Columbia, Vancouver, BC, Canada, in 1999.

ACI FELLOW OF THE INSTITUTE

Individuals were first elected to be an ACI Fellow of the Institute in 1973.

The Bylaws provide that Fellows are nominated by a Fellows Nomination Committee and elected by the Board of Direction. Potential candidates may be presented to the Fellows Nomination Committee for its consideration by a member of the Committee, by a local chapter, by the International Advisory Committee, or by petition by five current ACI Members. At the time of nomination, a Fellow shall have been a Member of the Institute, or a representative of an Organizational or Sustaining Member of the Institute, for at least fifteen years, including three of the last five years. A Fellow shall have made outstanding contributions to the production or use of concrete materials, products, and structures in the areas of education, research, development, design, construction, or management. In addition, a Fellow shall have made significant contributions to ACI through committees and/or local chapters. A Fellow shall retain that membership rank as long as membership in the Institute is maintained or until elected an Honorary Member. Nominations for deceased individuals will not be considered. Staff members will no longer be considered.

ASA member, Jacques Bertrand is elected among the newest Fellows for 2024.

THE AMERICAN CONCRETE INSTITUTE (ACI) ANNOUNCES THEIR 2024-2025 OFFICERS

Michael J. Paul has been elected to serve as president of the Institute for 2024-2025 and Scott M. Anderson has been elected ACI vice president for a two-year term. Additionally, four members have been elected to serve on the ACI Board of Direction, each for three-year terms: Corina-Maria Aldea, James H. Hanson, Werner K. Hellmer, and Enrique Pasquel.

ACI SHOTCRETER CERTIFICATION UPDATE

ACI Certification Committee C660 – Shotcreter Certification, formerly known as Shotcrete Nozzleman Certification, has approved the terminology change from Nozzleman to Shotcreter. This will be a global change across the program, including upcoming updates to all ACI 506 documents as they come online. This change is already reflected on both ACI and ASA's websites and Certification Policies and all certification materials.

The CP60 – Shotcreter Certification workbook, is currently under revision to incorporate both the updated CCS-4(20): Shotcrete for the Craftsman and the new shotcreter term. The Spanish translation of the CP60 is also currently under revision to incorporate the updated CCS-4(20). However, "shotcreter" is not a factor as the term in Spanish is not gender-biased. When these updated workbooks are issued, the corresponding updated shotcreter written exam will also be released for use in shotcreter certification sessions.

Additionally, a revision to their recertification policy was also approved. The requirement to show 1000 hours has changed to 500 hours within the last two years for those pursuing recertification with an oral interview rather than retaking the written exam. Those recertifying both in either both processes (wet- and dry-mix) or orientations (vertical and overhead) will need to provide at least 100 hours in each process and orientation they are pursuing. The Committee found 500 hours to be adequate and should ease the experience demands on those recertifying and desiring to take an oral exam on shotcrete knowledge instead of the written exam.

ACI SHOTCRETE INSPECTOR CERTIFICATION UPDATE

ACI Certification Committee C661 – Shotcrete Inspector Certification, the certification committee overseeing the shotcrete inspector certification program has approved a policy change to the program. The Committee voted to approve both ACI CSA-Standards Field Testing Technician certification (or recent written exam) and/or CCIL Basic Concrete Field Type QF certification (or recent written exam) as allowable equivalents to the ACI Concrete Field Testing Technician – Grade I program as a requisite component of Shotcrete Inspector. It is expected that these changes would greatly reduce barriers to ACI Shotcrete Inspector certification mainly in Canada, where the USA's ASTM-based field testing program is not commonly held by technicians or potential inspectors.

ICRI ELECTS NEW OFFICERS AND BOARD MEMBERS

The International Concrete Repair Institute (ICRI) announced its new officers and board members for the calendar year 2024 with Brian MacNeil, from Mac & Mac Hydrodemolition Services Inc., as its President. To support MacNeil, the ICRI membership also elected the following officers: ICRI President-Elect Gerard Moulzolf, American Engineering Testing, Inc.; ICRI Vice President David Karins, Karins Engineering Group, Inc.; Treasurer Natalie Faber, Aquafin, Inc.; and Secretary Dan Wald, Beacon/Coastal.

Pierre Hebert, Sika Canada, who served as 2023 President, will continue his service on the Board as Immediate Past-President.

APPLIED INDUSTRIAL TECHNOLOGIES ACQUIRES CANGRO INDUSTRIES/RFI CONSTRUCTION PRODUCTS

Applied Industrial Technologies (NYSE: AIT) is pleased to announce the acquisition of Cangro Industries, Inc./RFI Construction Products which will become part of Applied's U.S. Service Center network under the new name Cangro Industries An Applied Company. AIT is a leading value-added distributor and technical solutions provider of industrial motion, fluid power, flow control, automation technologies, and related maintenance supplies. Founded in 1960, Cangro adds a full line of equipment, accessories and replacement parts for the specialty cement industry to AIT. Cangro also provides technical assistance for custom-built equipment for the placement of gunite, shotcrete, mortar, stucco, and plaster. Cangro Industries an Applied Company operates with a team of more than 20 associates from two locations, and is based in Farmingdale, New York. AIT, with its corporate headquarters in Cleveland, OH, has over 600 service centers and 12 distribution locations. We welcome Cangro Industries An Applied Company to the AIT network in a continuing effort to optimize our local presence and provide our customers with leading technical support. For product information visit: rficonstructionproducts.com

SHOTCRETE ONLINE

Public access to the electronic version of Shotcrete magazine is available from www.shotcrete.org. To ensure notification of new issues, subscribe via **shotcrete.org/news/asa-e-newsletter-subscribe/**

SHOTCRETE CALENDAR

Please check with the meeting provider as some meetings may be postponed or cancelled after publication of this issue of Shotcrete.

JUNE 9, 2024	**ASTM Workshop on Next Generation Cements and SCMs: Towards Specification** Philadelphia Marriott Downtown | Philadelphia, PA
JUNE 9 - 12, 2024	**ASTM Committee Meetings – C09 Concrete and Concrete Aggregates** Philadelphia Marriott Downtown | Philadelphia, PA
JUNE 23 - 26, 2024	**North American Tunneling Conference (NAT 2024)** Nashville, TN
SEPTEMBER 23, 2024	**Recognizing Quality Shotcrete** ACI Mid-Atlantic Resource Center | Columbia, MD
OCTOBER 3, 2024	**Recognizing Quality Shotcrete** ACI SoCal Resource Center | San Bernardino, CA
OCTOBER 24, 2024	**Recognizing Quality Shotcrete** ACI MidWest Resource Center | Elk Grove Village, IL
NOVEMBER 2, 2024	**ASA 2024 Fall Committee Meetings** Location TBD | Philadelphia, PA
NOVEMBER 3 - 7, 2024	**ACI 2024 Fall Concrete Convention** Philadelphia Marriott Downtown | Philadelphia, PA
NOVEMBER 12 - 14, 2024	**International Pool | Spa | Patio Expo 2024** Kay Bailey Hutchison Convention Center | Dallas, TX
DECEMBER 8 - 11, 2024	**ASTM Committee Meetings – C09 Concrete and Concrete Aggregates** Philadelphia Marriott Downtown | Philadelphia, PA
JANUARY 21 - 23, 2025	**2025 World of Concrete** Las Vegas Convention Center | Las Vegas, NV
MARCH 9 - 11, 2025	**2025 Shotcrete Convention & Technology Conference** The DeSoto | Savannah, GA
MORE INFORMATION	To see a full list, current updates, and active links to each event, visit **www.shotcrete.org/calendar**.

ASSOCIATION NEWS

ASA LAUNCHES NEW WEBSITE!

Shotcrete.org has a new look! Redesigned to enhance navigation both online and through your mobile device, ASA's redesigned website brings you easier access to ASA and improves your user experience. Highlights include:

- Portals directly to key application segments including Pool, Repair, Architectural, Underground, Structural, International, Recreational
- Buyers Guide – link is now located directly from our home page (upper right corner) and real time updates with our database.
- Enhanced keyword search capabilities for articles, FAQs, and awards.
- Upgraded calendar with filtering capabilities

Visit shotcrete.org today and find the resources for your shotcrete needs!

2024 ASA SHOTCRETE CONVENTION AND TECHNOLOGY CONFERENCE

Lakeway Resort and Spa | March 3 – 5, 2024

SHOTCRETE CONVENTION & TECHNOLOGY CONFERENCE

The 2024 ASA Shotcrete Convention and Technology Conference welcomed over a hundred attendees! This year's event took place at Lakeway Resort and Spa, nestled in the Texas Hill Country along the shores of Lake Travis. Our annual convention featured three tracks, consisting of 16 different sessions, in addition to committee meetings and networking opportunities. The conference concluded with our annual awards banquet held on Tuesday evening, where we celebrated the achievements of the 2023 Outstanding Shotcrete Project Award recipients.

Stay tuned for the Call for Presentations for our next convention, to be held at The Desoto in Savannah, GA, from March 9 - 11, 2025.

asa OUTSTANDING SHOTCRETE PROJECT Awards

CALL FOR ENTRIES FOR 2024 OUTSTANDING SHOTCRETE PROJECT AWARDS PROGRAM

2024 marks the 20th anniversary of ASA's Outstanding Shotcrete Project Awards program. These awards feature the amazing benefits of using shotcrete in concrete projects. Projects can be submitted in the following six categories: architecture/new construction, infrastructure, international projects, pool & recreational, rehabilitation & repair, and underground. Submit your project by October 1, 2024. Details on the Outstanding Shotcrete Projects Awards program and details on the past winners can be found at www.shotcrete.org/Awards.

ASA @ WORLD OF CONCRETE 2025

SAVE the DATE: January 21 – 23, 2025
Las Vegas Convention Center | Las Vegas, NV

asa | WORLD OF CONCRETE®

ASA proudly serves as an official cosponsor of the World of Concrete (WOC), supporting the concrete and masonry industries for over 50 years. Throughout WOC's annual convention, participants are invited to engage in shotcrete education sessions and discover more about ASA at our General Membership Meeting and Reception. Once registration opens, you can secure discounted exhibition passes using source code A17 and be sure to drop by our exhibit booth to connect with us. Keep in mind, it's never too early to start preparing for WOC. Save the date on your calendars today!

2024 ASA OFFICERS AND BOARD OF DIRECTORS APPOINTMENTS

ASA announced its new officers and Board members, elected by the membership, during the annual convention held earlier this year. Oscar Duckworth, Applied Shotcrete, will serve a 1-year term as ASA President. Frank Townsend, Patriot Shotcrete & Construction, assumes the position of Past President. To complete the Executive Committee, the ASA membership also elected the following for 1-year terms: William "Bill" Geers, Bekaert, as Vice President; Jason Myers, Dees Hennessey Inc., as Secretary; and Kevin Robertson, Sika - Shotcrete Tunneling & Mining, as Treasurer.

Newly elected ASA Directors, serving three-year terms: Randle Emmrich, Coastal Gunite Construction Company; Christoph Goss, Schnabel Engineering; and Bruce Russell, CROM LLC serving a 2nd consecutive term. New ASA Director, Mike Klemp, Thorcon Shotcrete & Shoring, LLC will serve a 1-yr term, replacing Dennis Bittner. Returning ASA Directors include with 2 years remaining: Juanjose Armenta-Aguirre, Gunite Supply & Equipment Co; Mark Bradford, Spohn Ranch Skateparks; and Justin Shook, Baystate Shotcrete LLC. Jamie Curtis, CCP Shotcrete + Pumping; and Derek Pay, Oceanside Construction, both have one year remaining.

To support the mission and work of ASA, the following individuals serve as Chairs of ASA Committees: Marcus von der Hofen, Coastal Gunite Construction Company, Contractor Qualification Committee; Derek Pay (newly appointed), Oceanside Construction, Education & Safety Committee; Jason Myers, Dees-Hennessey Inc., Membership & Marketing Committee (newly merged); Ryan Oakes, Revolution Gunite, Pool and Recreational Committee; Lihe "John" Zhang, LZhang Consulting & Testing Ltd., Technical Committee; and Christoph Goss, Schnabel Engineering, Underground Committee.

Committee meetings are open to the public and ASA welcomes and encourages the participation of all interested parties in the shotcrete industry. Upcoming committee meetings can be found online under ASA Calendar. For more information, visit www.shotcrete.org.

SHOTCRETE FAQs

As a service to our readers, *Shotcrete* magazine includes selected questions and answers by the American Shotcrete Association (ASA). Questions can be submitted to info@shotcrete.org. Selected FAQs can also be found on the ASA website at **www.shotcrete.org/FAQs**.

Question: *We are the structural engineer of Record (SEOR) on a project where the shotcrete subcontractor waited too long between shooting the concrete layers, as the inspector has noted that the first layer was too dry. We have now required the subs perform a tensile or bond strength test. However, I do not see anywhere in the ASTM an approximation of the capacity of the bonding between concrete. I am aware that it varies due to curing time. Do you have any graphs or place you can direct me to find this answer?*

Answer: We can typically expect at least 150 psi (1 MPa) bond tensile strength on shotcreted material on hardened concrete (cast concrete or shotcrete placement). PCA Research in the mid 1950's provided research that found that the bond SHEAR stress above 200 psi (1.4 MPa) in a bonded overlay produced adequate strength for satisfactory service. Research shows that to estimate the bond shear strength one should multiply the bond tensile strength by at least 2 to 3.

Here are some relevant articles that may help you better evaluate the bond shear strength needed for the construction joint to act monolithically.

- The Shotcrete magazine article "Shotcrete Placed in Multiple Layers does NOT Create Cold Joints" addresses the bond strength between shotcreted layers. (shotcrete.org/articles – search for "Hanskat Cold Joints")
- "Concrete Q&A: Tensile Bond Strength of Concrete" (Concrete International - July 2018 – www.concrete.org) by Scott Tarr. This was a reply to an inquiry about a cast, not shotcreted, overlay. The article references the 200 psi bond SHEAR strength from PCA research, and research by Silwerbrand research that concluded one could multiply the bond tensile strength by 1.9 to 3.1 for the equivalent bond shear strength on cast overlays.
- "Bond Strength Between Shotcrete Overlay and Reinforced Concrete Base" (ICRI Concrete Repair Bulletin Jan/Feb 2016 – www.icri.org – search "Sprinkel") by Michael Sprinkel This article was specifically for shotcrete overlays and again references the bond SHEAR strength as 200 psi and concludes that with shotcrete overlay "The ratio between shear and tensile bond strength is about 3 to 4 for surfaces with a macro texture of 0.06 in. (1.5 mm) and increases as the macro texture increases to a ratio as high as 7. Shear bond strength increases as the shear strength of the base concrete increases, but the correlation is not good.
- "Resurfacing And Patching Concrete Pavement with Bonded Concrete" by Earl Felt (Proceedings of the Thirty-Fifth Annual Meeting of the Highway Research Board, V. 35, 1956). This is the original research where the 200 psi bond shear strength research was originally presented.
- "Shear bond strength in repaired concrete structures" (2003) by J Silfwerbrand (Materials and Structures, V. 36, No. 6, July 2003). This presents the research that concludes "On cast-in-place objects, the ratio between average shear stress and average tensile stress varies between 1.9 and 3.1. On shotcrete objects, corresponding ratio varies between 2 and 7."
- ICRI 210.3 "Guide for Using In-Situ Tensile Pull-Off Tests to Evaluate Concrete Surface Repairs and Bonded Overlays" (2022). Chapter 4 - Acceptance Criteria has good guidance. Sections 4.4 Variability of Results and 4.5 Comparison of Tensile Pull-off and Direct Shear Strengths may be particularly helpful in evaluating the results of the bond tensile tests. ICRI 210.3 is available as a PDF at ICRI.org.

Question: *Does a shotcrete mixture require fly ash?*

Answer: Shotcrete is a placement method for concrete. For wet-mix shotcrete placement we need concrete mixtures that are still pumpable at relatively low slumps (2 to 4 in. [50 to 100 mm] through small diameter (1.5 to 2 in. [38 to 50 mm]). Fly ash is a commonly used supplementary cementitious material that is added to concrete mixtures to replace a portion of the portland cement. Fly ash has these benefits:

1. It is a recycled material and thus has a lower impact on CO_2 generation.
2. It is used to replace 15 to 25% of portland cement though some projects have replaced up to 50%.
3. Its rounded particle shape helps reduce pumping friction and pressure in the delivery line.
4. It is smaller than portland cement grains and thus can reduce permeability and slow corrosion.
5. It slows the set to allow a longer window for finishing that is helpful in hot weather.
6. Class F fly ash can help reduce issues with alkali-silica reactivity (ASR).

Question: *I am working on a reflecting pool repair project. We need to repair existing poured concrete pool walls. Do we need to place wire fabric or rebar into the existing concrete walls to have shotcrete adhere and repair the pool wall. Or could we just spray shotcrete over the existing concrete walls as a repair.*

Also, the existing reflecting pool floor has many expansion joints in it. Can shotcrete be used as a repair over existing concrete that has expansion joints in it?

Answer: Shotcrete placement onto existing concrete substrates provides an excellent bond. However, the surface preparation, reinforcing, placement and curing are important for providing the best structural integrity. Depending on the depth of the new shotcrete placement you may consider mechanically tying the shotcreted layer back to the sound concrete of the existing wall with epoxy or mechanically embedded anchors or j-bolts. Thicker sections may also benefit from the use of a steel wire mesh or fibers.

When shooting onto existing concrete the surface must be properly prepared and then shotcreted with quality shotcrete materials, equipment and placement techniques. Shotcrete placed onto an existing concrete surface will provide an excellent bond IF the following conditions are met:

- Make sure the surface is roughened and clean. The amplitude of roughness should be +/- 0.10 in. (2 mm) or more.
- A high-pressure water blaster (5000 psi [34 MPa] or more) or abrasive blasting can help to roughen and clean the surface.
- Bring the concrete substrate surface to a saturated surface dry (SSD) condition. This means the surface feels damp, but water is not picked up on a hand.
- Make sure the shotcrete placement is properly executed with high-velocity placement and quality materials.
- The shotcrete should have a minimum 28-day compressive strength of 4000 psi (28 MPa).
- Use of an ACI-certified shotcreter (formerly called shotcrete nozzleman) is recommended.
- No bonding agent should be used. It will interfere with the natural bonding characteristics of shotcrete placement.

A Shotcrete magazine article "Shotcrete Placed in Multiple Layers does NOT Create Cold Joints" discussing bond of shotcrete layers can be found at shotcrete.org and conducting a search with "Hanskat Cold Joints."

On the question about expansion joints, we can provide both expansion and contraction joints. In repaired sections over an existing wall, joints in the shotcrete layer(s) should be included at the same locations as the existing joints. If joints in the shotcrete are not aligned with the original wall joints, as the existing wall expands or contracts the movement will create cracks that mirror through at the shotcrete.

Question: *Is there a downside to using 3/8 in. (10 mm) round coarse aggregate as opposed to 3/8 in. irregular?*

Answer: A rounded rock coarse aggregate in a shotcreted concrete mixture should pump easier, though the amount of paste is the biggest factor for pumpability. As long as the round rock is appropriate for use in concrete it should be fine for shotcrete placement. The slump may trend a little higher with round rock at a given w/cm, but since your concrete supplier delivers at the ordered slump (hopefully!), placement should be similar.

Disclaimer: The technical information provided by ASA's technical team is a free service. The information is based on the personal knowledge and experience of the ASA technical team and does not represent the official position of ASA. We assume that the requester has the skills and experience necessary to determine whether the information provided by ASA is appropriate for the requester's purposes. The information provided by ASA is used or implemented by the requester at their OWN RISK.

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