shotcrete MAGAZINE

A quarterly publication of the American Shotcrete Association

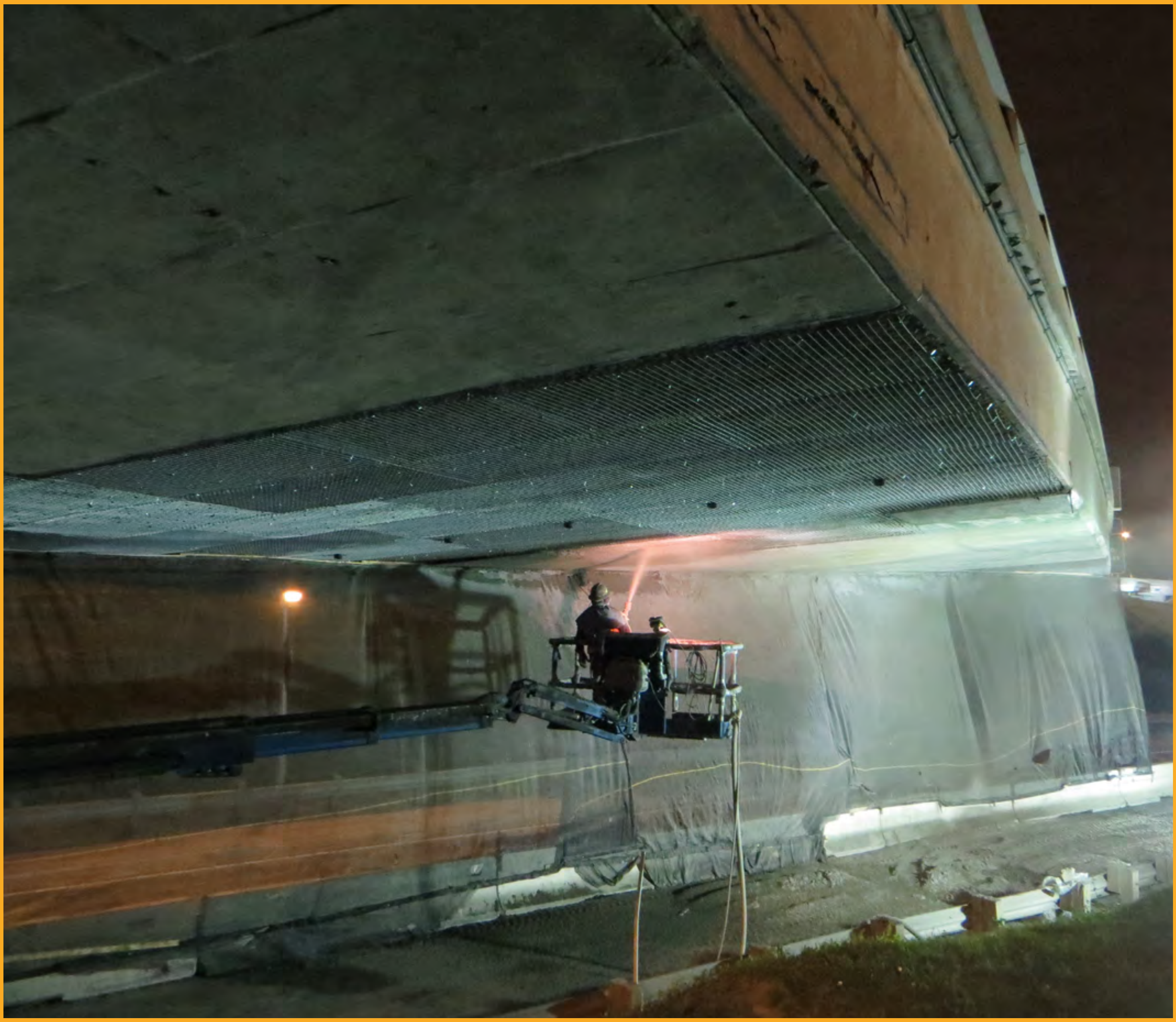
VOLUME 24, NUMBER 3 • 3RD QUARTER | 2022

www.shotcrete.org

SHOTCRETE MATERIALS

american shotcrete association asa

25 Century Blvd, Ste 505, Nashville, TN 37214 ELECTRONIC SERVICE REQUESTED

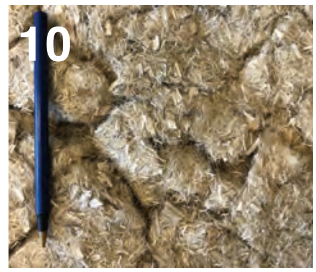


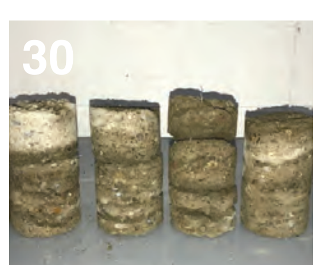
american shotcrete association | asa

shotcrete MAGAZINE

Volume 24, Number 3 • 3rd Quarter 2022

FEATURES





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

American Shotcrete Association
401 Edgewater Place, Suite 600
Wakefield, MA 01880
Phone: 248.963.0210
E-mail: info@shotcrete.org
Website: **www.shotcrete.org**

To unsubscribe, please go to **www.shotcrete.org/products-services-information/e-remove/**

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).

Executive Director
Charles Hanskat

Editor-in-Chief
Charles Hanskat

Managing Editor
Tosha Holden

Senior Editor
Alice McComas

Graphic Design
Marci Moon
Lynette Zeitler

DEPARTMENTS

Macro views of typical concrete mixture materials.
Photos Courtesy of Sika STM (Canada)

Looking Forward, ASA's Strategic Planning

By Lars Balck

Shortly after the turn of the century, the cement gun was invented. It was a big hit. Cement guns were purchased and copied by contractors around the world. At the time there were no standards and little mentorship. Soon poor workmanship led to failures which in turn caused many engineers to reject shotcrete altogether.

The first shotcrete committee, ACI 805, in 1951 published "Recommended Practice for the Application of Mortar by Pneumatic Pressure" and used the term "shotcrete" within the document. ACI Committee 805 soon became ACI 506. The first ACI 506 document was Symposium Paper 14 (SP-14). This SP had many excellent and still relevant papers detailing the shotcrete process. Over the last 60 years, the ACI 506 committee developed and maintained many shotcrete standards, guides, tech notes, and reports.

Yet many engineers are still not familiar with shotcrete placement and are hesitant to use it on their projects. As recently as a couple of years ago Cathy Burket in her President's Message related her experience with an engineer who absolutely refused to consider shotcrete on a project that would have clearly provided a superior repair while saving the owner time and money.

ASA was formed in 1998 to enhance the image and acceptance of shotcrete, unite the varying applications of the process, and provide a resource for education and accountability for quality placement in the industry.

This past October, ASA held a special meeting in Dallas to update our strategic plan and to provide a path forward for our Association. We invited a representative cross section of our membership – young, seasoned, contractors, suppliers, educators, and engineers. The meeting was facilitated by Virtual Inc (our association management firm).

The meeting was a great success. The group discussion was frank and lively, but also thoughtful and constructive. In the end, we all agreed on several major initiatives. The results/actions agreed to at the meeting will be reviewed and approved by the ASA Board. Some of the key points included:

- Attract more members, especially contractors
- Attract younger members
- Increase outreach to pool builders
- Improve the website to target application areas, making it a more user friendly portal
- Adapt to technological advances like mechanically assisted nozzles

In the end, what struck me most is the level of interest and involvement of the younger members. Going forward, the Association will be led by today's young members. They are the future of the Association, building upon the foundations we've established over our 25 years as an association. It was exciting to see the fresh ideas and perspectives they brought to the table.

The challenge for ASA, as with all associations and businesses, is the transition from one generation to another. Associations stagnate if the older generation refuses to consider the younger generation's ideas. We are fortunate to have a balanced collection of active members willing to accept new ideas yet not forget the past.

Today ASA is in good hands with the involvement of the younger generation and the understanding of the veteran contractors. The future looks bright. We have the best association staff of any association. Led by our Executive/Technical Director, Charles Hanskat, who has spent countless hours presenting shotcrete seminars across North America and working with standards-developing organizations to properly include shotcrete in their documents. Alice McComas, our Assistant Director, is the organizer who keeps the Association running while administering the massive shotcrete nozzleman certification program. Tosha Holden, who manages our Shotcrete magazine and social media output, is getting the word out about shotcrete in print and many digital channels. Tosha also runs the annual ASA Outstanding Shotcrete Awards program, highlighting the ingenuity, creativity, and cost-savings of shotcrete.

With the combination of our dedicated staff's efforts and the work of our active volunteers participating as officers, directors, and committee members, ASA is **THE** source for knowledge and networking for all involved in the shotcrete industry. ASA programs such as shotcrete nozzleman certification, shotcrete contractor qualification, and shotcrete inspector education are improving shotcrete project quality and performance. That in turn increases opportunities for all our current and future shotcrete contractors. ASA members are passionate about the work they do, striving to improve, and willing to share their experiences and expertise to grow the industry. We invite you to join these efforts, connect with industry leaders, and make an impact on the quality of shotcrete placement in your sphere of the marketplace.

The future is bright for shotcrete.

COMMITTEE CHAIR MEMO

ASA Pool and Recreational Shotcrete

By Ryan Oakes, Chair

As I sit here, 3:40 AM, wide-eyed and thinking about the state of our industry, the swimming pool, watershape and skate park industries, over the last decade, much has been done to add value to our industry. In the decade to come what will we do to make changes, forge new paths, improve the industry and keep the shotcrete process strong and relevant in the pool and rec industries?

Shotcrete, both dry-mix and wet-mix processes, has become synonymous with swimming pools. Technology and economics have produced competitors, such as liner pools and fiberglass pools, but truly durable pools are still the domain of concrete. The last 50 years have shown us that concrete pools and skate parks can be temporary or essentially permanent, depending on their build quality.

Nearly 25 years ago, concerned contractors, material suppliers, equipment suppliers, engineers and researchers came together to form the American Shotcrete Association (ASA), an organization centered around promoting standards and raising quality for shotcrete placement. Over time, ASA developed committees of members to focus on the different subsets of the shotcrete industry, such as Underground, and Pools as well as Safety and other subject matter. Since its inception, ASA has helped promote the quality shotcrete placement in pools and skateparks. Members have contributed articles sharing their expertise, knowledge and raising the bar in an industry where the bar was once low.

The Pool and Recreational Shotcrete Committee has created 7 position statements establishing the industry standard for shotcrete placement in the pool construction. These have recently been updated, reissued in *Shotcrete* magazine and listed here:

1. Compressive Strength Values of Pool Shotcrete
2. Shotcrete Terminology
3. Sustainability of Shotcrete in the Pool Industry
4. Watertight Shotcrete for Swimming Pools
5. Monolithic Shotcrete for Swimming Pools (No Cold Joints)
6. Forming and Substrates in Pool Shotcrete
7. Curing of Shotcrete for Swimming Pools

Much has been done in the last 20 years to lay the foundation for what is to come.

As Chairman of the Pool and Recreational Shotcrete Committee, I have been handed a torch to carry and with that torch, a great deal of responsibility to forge new roads in

ASA POOL AND RECREATIONAL SHOTCRETE COMMITTEE

Ryan Oakes, Chair | Revolution Gunite
Mike Reeves, Secretary | Gunite Specialists Inc

Nadia Alexandre |AAA Shotcrete Inc
Juanjose Armenta-Aguirre | Gunite Supply & Equipment Co
Christopher Brosche | Calabash Outdoors
J Ryan Casserly | Westport Pools
Robert Cavaliero | EdenCrete
Jonathan Dongell | Pebble Technologies Inc.
William Drakeley | Drakeley Industries LLC
Andy Duck | Artisan Concrete Services, Inc.
Mason Guarino | Baystate Shotcrete LLC
Brett Holland | Holland Aquatics
Gerald Koutavas | Kordsa Inc
Jesse McDowell | McDowell Shotcrete Inc
Greg McFadden | Prestige Gunite and Shotcrete Inc
Curtis Mills | PDQuipment
David Peterson | Watershape University
Raymond Schallom| RCS Consulting & Construction Co Inc
Marcus von der Hofen | Coastal Gunite Construction Company
Frank Townsend| Patriot Shotcrete & Constructors
Rocky Wisley | Serenity Hardscapes, LLC

our industry. I ask myself: how will I lead this committee; how can we raise the bar further; and most importantly, how will we serve our industry?

In the last two years the swimming pool sector has experienced immense growth. Demand has far outpaced supply and with that, we see new entrants to the market. New pool contractors and new sub-contractors, many of whom have very little experience or knowledge, not only of pools but of every component of pool construction, especially shotcrete.

My first goal as chairman is to continue where our committee has left off, to see that our current agenda is prioritized and carried out. This includes continuing to build a library of resources for our industry with our Pool Position Statements. The two position statements currently in progress are on Reinforcement and Rebound.

My next goal as chairman is to foster outreach and continue to educate our industry partners and end users alike. Through education, we can solidify the shotcrete process as the best method to create strong and durable pools, built to last 50 to 100 years. This includes working with staff to update and improve the presence of Pool and Recreational Shotcrete references and resources on the ASA website, promoting it as a valuable resource for the industry. The ASA seminar, *Quality Shotcrete – How to Recognize It When You See It*, originally developed as part of the ACI Shotcrete Inspector program, is also very appropriate for pool builders and owners. This seminar has been offered at trade shows such as the International Pool | Spa | Patio Expo and has been greatly received. Helping owners know how to recognize quality shotcrete and equipping shotcrete contractors to better communicate the quality of their work to inspectors and owners is a win-win for the industry!

My last goal as chairman is to see our pool industry elevated to the point that the majority rather than the minority of pools are well constructed. Towards that end, we will be working closely with ASA's Contractor Qualification committee to introduce a Pool component to the Qualified Shotcrete Contractor program. Recognizing that pool contractors work within different parameters than some other types of structural concrete, a pool-specific qualification would allow experienced pool shotcreters with quality applications as a priority, to distinguish themselves from those who value quantity over quality. Similarly, it gives the public a means to make informed choices regarding contractor options in the market.

We have an excellent group of committed volunteer members that make up our Pool and Recreational Shotcrete Committee and I encourage anyone that has an interest in serving on the committee to reach out to info@shotcrete.org. Watch our calendar and join us at our Committee meeting in Ojai, CA at ASA's 2023 Convention in February 2023.

Where in the World was ASA in 2022?

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

I'm writing this as the end of 2022 approaches. It's been a busy year for us at ASA. So, where has ASA worked to advance shotcrete?

In January, the annual Transportation Research Board (TRB) conference held in Washington, DC, had several members advocating for shotcrete in the various concrete committees. Also, ASA exhibited and held several education sessions and a nozzleman certification at the annual World of Concrete in Las Vegas. Attendance overall was down from the usual WOC crowds due to COVID. It was great seeing our members and others in the concrete industry face-to-face again.

In February, we held our annual ASA Technical Conference and Convention at the Sonesta resort in Hilton Head, SC. We had good weather, at least in comparison to the weather back home for those of us in the northern states and Canada. Our members and guests took over the hotel meeting space, where we enjoyed the many technical sessions, exhibits, and committee meetings. We also held our full-day Shotcrete Contractor education seminar, which was very well attended. Overall, a great event. Thanks again to all our sponsors, speakers, and attendees who made it a super networking event.

March had many ASA members actively participating in the shotcrete-related American Concrete Institute (ACI) committee meetings held in Orlando, FL. Our members are leading contributors to ACI 506 (Shotcrete), C660 (Shotcrete Nozzleman Certification), and C661 (Shotcrete Inspector Certification). Our members also contributed to many other ACI committees, including ACI 301 (Structural Concrete Specification), ACI 318 (Structural Concrete Design Code), ACI 350 (Concrete Liquid-containing Code), ACI 544 (Fibers), ACI 562 (Concrete repair Code), and ACI 563 (Concrete Repair Specification).

April was the start of warmer weather and we saw our member's active involvement in the International Concrete Repair Institute's (ICRI) Spring Convention. Progress was made in getting shotcrete directly included in the ICRI 110 Guide to Specifying Concrete Repair, as well as in ICRI 320 documents that cover concrete repair methods, including shotcrete.

June was busy. ASA met with the American Railroad Engineers and Maintenance of Right-A-Way Association (AREMA) Concrete design and repair Committee 8 in Anchorage, AK. Immediately after the AREMA meeting, many of our members participated in ASTM's summer concrete committee (C09) meetings in Seattle and a week later attended the North American Tunneling Conference in Philadelphia. The Underground Construction Association (UCA), part of the Society of Mining, Metallurgy and Exploration (SME) has many ASA members participating in the shotcrete-specific committee (WG12) that is the US representative of the International Tunneling. All the meetings and conferences were well attended, with good visibility for shotcrete in the concrete world.

July, August, and September were fairly quiet meeting-wise. Time to enjoy the summer weather.

October was a big month for ASA. We held a special Strategic Plan Update meeting in Dallas, TX, on October 21, with our ASA Committee meetings the next day. See the President's Memo for highlights of these meetings. After our ASA meetings, many of our members went on to attend ACI's Fall Convention. As in the Spring meeting, our members are actively advocating for improved shotcrete inclusion in various ACI technical and education documents.

November was also a busy month. ASA was again highly involved in various ICRI technical committees. I presented a session on Shotcrete for Blast and Emergency Repairs. Immediately following the ICRI meeting, we attended the International Pool Spa Patio (IPSP) exhibition, where we presented two full-day seminars. One for shotcrete nozzlemen and the other for pool contractors and owners about Recognizing Quality Shotcrete, Know it When You See It." We also had members actively involved in seminars presented for Watershape University at the IPSP show.

Finally, in December, we attended the Winter ASTM meeting in New Orleans, LA. Good progress was made in the ASTM C09.46 Shotcrete committee meeting, where shotcrete-specific testing and materials standards are developed and maintained.

ASA sponsored ACI shotcrete nozzleman certification sessions were also extremely busy throughout the year. All our sessions were in the USA and Canada. In summary, in 2022 we had 86 sessions, with 296 new certifications, 73 nozzlemen-in-training, and 203 recertifications. Overall, a record number of certifications in the year. We also hosted seven shotcrete inspector education seminars with 42 attendees. Two of the sessions were hosted at the Southern California ACI Resource center. The shotcrete inspector teaches the attendees the aspects of shotcrete placement that are essential for quality concrete.

Looking forward to 2023, we anticipate another busy year in the nozzleman and inspector seminars. We have already scheduled four inspector seminars at ACI Resource Centers. Two again in Southern California and two in the Midwest Resource Center in Chicago. And we will again present at the IPSP exhibition in Fall. Nozzleman certifications appear steady. We also are potentially going to renew our education and certification efforts in conjunction with the Concrete Pumping Association of Australia. We have not been able to schedule sessions over the last three years as Australia shut down travel due to COVID, however we are looking to do so in the future.

Through our involvement, you can see that ASA strongly advocates for shotcrete's proper inclusion in a wide variety of codes, standards, guides, and reports. These are the source documents owners and engineers use to design and construct all types of concrete structures. We are making great strides in the acceptance and proper inclusion of shotcrete due to the active involvement of our members. Thanks to all our members who so freely give of their time and effort to move shotcrete forward.

Performance Evaluation of a Natural Fibre on Rebound in a Steel Fibre-Reinforced Wet-Mix Shotcrete

By Jean-Benoît Darveau and Marc Jolin

INTRODUCTION

For several years, many efforts have been made to reduce the ecological footprint of concrete, the most used construction material in the world. Hence, any improvements are significant; this is why processed natural fibre developed for use in concrete and shotcrete have received some attention lately. Indeed, manufacturers' claims are quite interesting, ranging from ease of mixing to improved durability, already demonstrated that natural hemp-based fibre has a lot of beneficial impact on several fresh concrete properties, such as pumpability, early plastic shrinkage, finishing ability, and built-up thickness (for use in shotcrete), without having negative impacts on hardened concrete properties such as compressive strength and permeability. Likewise, Gagnon and Jolin (2019) also reported that a natural fibre produced by *NRF & Co. (NRF)* has beneficial impacts on the finishing ability and the built-up thickness, without having negative impacts on the compressive strength. Realizing that these natural fibres enhance the cohesion of the fresh shotcrete, it is obvious that the next question is: what about the rebound? The reduction of rebound in shotcrete technology has always been at the center of our shotcrete research, as it represents a significant loss, both environmentally and financially.

Therefore, the *Centre de recherche sur les infrastructures en béton* (CRIB) at *Université Laval* has been mandated to evaluate the capacity of the natural NRF fibre, when added to a steel fibre-reinforced wet-mix shotcrete (SFRS), to reduce rebound. Its impact on the compressive strength of non-reinforced concrete and wet-mix shotcrete had already been successfully assessed (Gagnon and Jolin, 2019). It was now time to evaluate the impact on the flexural strength, via the *pr EN 14488-3 Testing sprayed concrete – Part 3: Flexural strengths (first peak, ultimate and residual) of fibre reinforced specimens – Method B (3PBT).*

MIX DESIGN

Two steel fibre-reinforced wet-mix shotcretes were produced to evaluate the performance of the natural NRF fibre (Fig. 1), one with, and one without the addition of the fibre. The base mixture contained ordinary portland cement, fly ash, and silica fume. It is important to note that no set accelerator was used in this project as the wet-mix shotcrete mixture had sufficient in-place stiffness for proper placement and finishing.

Fig. 1: Natural fibre produced by NRF & Co.

Table 1 presents the mix design of both mixtures, with the addition of the natural fibre (SFRS-N), and without it (SFRS). The only differences between the two mixtures were the presence of the natural fibre and small variations in the dosage of admixtures. The steel fibre content for both mixtures was 40 kg/m³ (67 lb/yd³) and the natural fibre content for the SFRS-N was 1 kg/m³ (1.7 lb/yd³). The admixtures used were an air entraining admixture (AEA) and a mid-range water-reducer (MRWR). It should be noted that air entrainment is commonly used in the industry to facilitate pumping; the in-place air content is greatly reduced upon impact onto the receiving surface as presented in *Guide to Shotcrete (ACI PRC-506-16)*. The water to cement ratio was 0.40 and the 28-day compressive target strength was 50 MPa (7250 psi).

Mix design			
Component	Unit	SFRS-N	SFRS
Steel fibre dosage	kg/m³ (lb/yd³)	40 (67)	40 (67)
Natural fibre dosage	kg/m³ (lb/yd³)	1 (1.7)	0
Cement	kg/m³ (lb/yd³)	381 (642)	382 (644)
Silica Fume	kg/m³ (lb/yd³)	29 (49)	29 (49)
Fly Ash	kg/m³ (lb/yd³)	72 (121)	72 (121)
Water	kg/m³ (lb/yd³)	201 (339)	201 (339)
Sand	kg/m³ (lb/yd³)	1072 (1807)	1073 (1809)
Coarse aggr. (10 mm, 3/8 in.)	kg/m³ (lb/yd³)	575 (969)	576 (971)
AEA	ml/m³ (oz/yd³)	497 (13)	475 (12)
MRWR	ml/m³ (oz/yd³)	4974 (126)	3214 (83)

Table 1: Mix-design

PREPARATION OF SPECIMENS

The wet-mix shotcrete mixtures were produced at *Centre de recherche sur les infrastructures en béton* (CRIB) at *Université Laval*. The equipment used was an *Allentown/Putzmeister Powercreter 10* pump shown in Fig. 2, hooked up to 15 m (50 ft) long rubber hose, having a 50 mm (2 in.) interior diameter. It was equipped with an integrated mixer allowing batch sizes ranging from 80 to 120 l (20 to 30 gal) and two high-pressure hydraulic pistons. This equipment is similar to what is usually used in the industry with the exception of the electric motor that replaces the usual diesel motor.

Six panels of 150 x 600 x 600 mm (6 x 24 x 24 in.) [for the evaluation of the flexural tensile strength (to pr EN 14488-3 – 3PBT)] and one standard test panel with sloped sides [for the evaluation of the compressive strength (to ASTM C1604), the boiled water absorption, and volume of permeable void (to ASTM C672)] were prepared for each mixture.

Fig. 2: Allentown Powercreter 10 wet-mix process shotcrete pump

For shotcreting operations, the end of the hose was mounted to a 50 mm (2 in.) nozzle. With this nozzle, compressed air is introduced through the air ring at 8 different locations around the circumference of the shotcrete stream.

Shooting operations took place in a rebound chamber and normal shooting techniques were observed according to *Guide to Shotcrete (ACI PRC-506R-16)* and *Craftsman Workbook for ACI Certification of Shotcrete Nozzleman (ACI CP-60 (15))*. Overall, the pumping and the spraying were conducted without any difficulties. The freshly sprayed panels were covered with a water-soaked burlap and a plastic film for a period of 24 hrs and were then demolded and stored in a curing chamber at 23°C (73°F) and 100% relative humidity. A few days before the testing date, the slabs were notched using a water-cooled diamond circular saw as in *pr EN 14488-3 – 3PBT.*

RESULTS

Fresh concrete properties

The fresh concrete properties, i.e., slump and air content, were measured at the discharge of the mixing hopper once the concrete was thoroughly mixed (5 min) and are presented in the Table 2. The slump test was conducted following the ASTM C143 – *Standard Test Method for Slump of Hydraulic-Cement Concrete*. The air content was determined before pumping following the *ASTM C138 – Standard Test Method for Air Content of freshly Mixed Concrete by the Pressure Method*. The slump for both mixtures were within the target range suggested in the *Guide to Shotcrete (ACI PRC-506R-16)*, i.e., 50 to 100 mm (2 to 4 in.).

Parameter	Mixtures	
	SFRS-N	SFRS
Slump, mm (in.)	55 (2.2)	60 (2.4)
Air content, %	6.4	8.8

Table 2: Fresh concrete properties

REBOUND

To evaluate rebound, the gradual development of concrete weight adhering to a vertical steel panel was recorded by the means of a data acquisition system, while the amount of material used was determined by measuring the concrete flow at the exit of the rubber hose. It is important to note that the way to measure the rebound in the concrete laboratory at *Université Laval* is rather severe, as the shotcrete is sprayed on a vertical steel panel which initially increases the rebound until a thin layer of 25 mm (1 in.) covers the panel. However, comparison between both mixes would be still acceptable.

For each mixture, two measures of rebound were taken and presented in Table 3. It appears that adding the natural fibres lowers the rebound by almost 25%. Morgan et al (2017) suggested that the enhanced adhesion and cohesion come from the reinforcing effect of the natural fibre which has a rough surface, and the fact that the hydrophilic fibre absorbs part of the free water.

Mixture	Rebound (%)		
	1	2	Average
With natural fibres (SFRS-N)	16.2	17.6	16.9
Without natural fibres (SFRS)	23.4	21.6	22.5

Table 3: Rebound of SFRS with and without natural fibres added

COMPRESSIVE STRENGTH

The compressive strength of both mixtures was measured from a set of three cores of 75 x 150 mm (3 x 6 in.), following ASTM C1604 – *Obtaining and Testing Drilled Cores of Shotcrete*. Table 4 presents the average 28-day compressive strength, the 95% confidence interval (represented by the standard error calculated with the estimate standard deviation of the sample, which have a population of 3) and the coefficient of variation (CV) of the mixtures. Both mixtures easily reached the compressive strength target of 50 MPa at 28-day, and the addition of natural fibres does not seem to have a negative impact on the compressive strength. In fact, a quick statistical test using the standard error shows that both average values are similar.

Mixture	Compressive strength at 28 days		CV
	MPa	psi	%
With natural fibres (SFRS-N)	59.2 ±5.1	8586 ±735	3.4
Without natural fibres (SFRS)	61.7 ±2.0	8847 ±288	1.3

Table 4: Compressive strength test results

FLEXURAL TENSILE STRENGTH ON NOTCHED PANEL (3PBT)

The flexural tensile strength of the mixtures was evaluated following *pr EN 14488-3 Testing sprayed concrete – Part 3: Flexural strengths (first peak, ultimate and residual) of fibre reinforced specimens – Method B (3PBT)*. Fig. 3A presents an overview of the setup used for testing the notched 600 x 600 x 100 mm slab. Fig. 3B shows a close-up of the setup with the specimen mounted. For the measure of the crack mouth opening displacement (CMOD), a clip gauge was used. Table 5 presents the average results of the test with the coefficient of variation.

Parameter	SFRS-N			SFRS		
	MPa	psi	CV	MPa	psi	CV
Limit of proportionality (*LOP*)	6.5	943	10.7 %	7.0	1015	14.5%
Residual flexural tensile strength 1 ($f_{R,1}$)	5.2	751	8.0%	5.5	798	10.4%
Residual flexural tensile strength 2 ($f_{R,2}$)	5.4	783	8.6%	5.7	827	9.2%
Residual flexural tensile strength 3 ($f_{R,3}$)	4.3	624	7.4%	4.2	609	8.0%
Residual flexural tensile strength 4 ($f_{R,4}$)	6.5	943	10.7 %	7.0	1015	14.5%

Table 5: 3PBT results

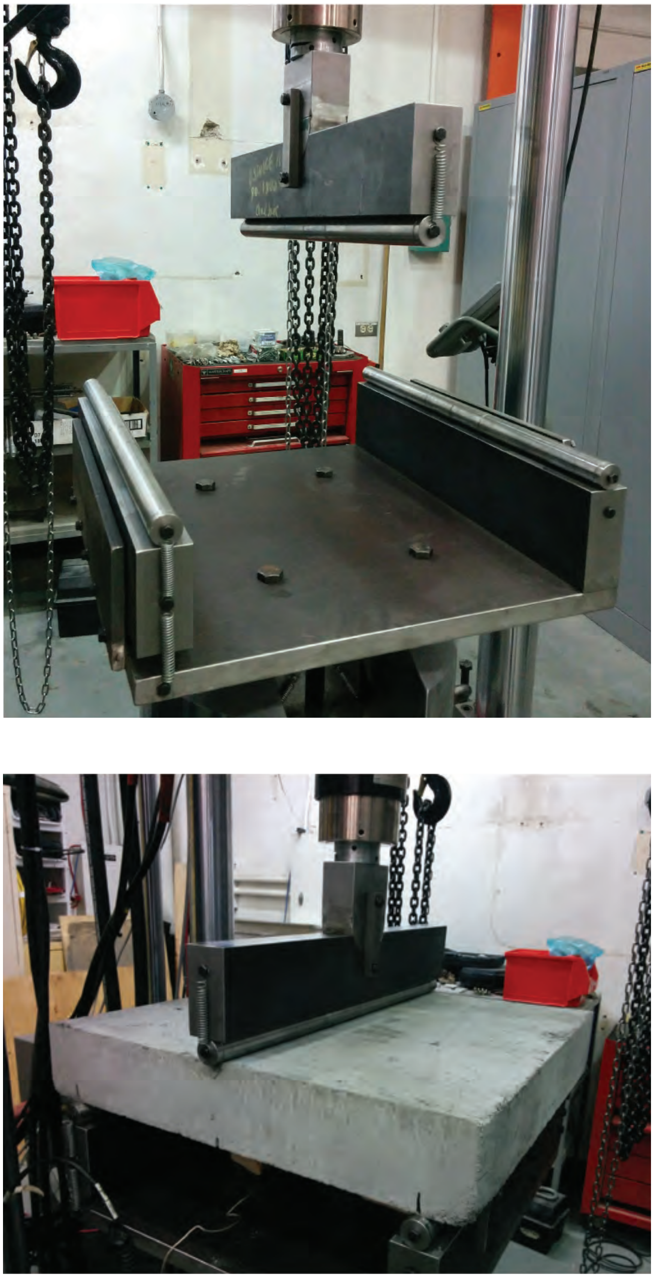


Fig. 3: A) Overview of 3PBT setup and B) close-up during testing

Fig. 4 presents a graph of the comparison between the values of flexural tensile strength, the Limit of Proportionality (LOP), and residual strength obtained for the SFRS-N and the SFRS mixtures. The error bars on the graph correspond to the standard error, for a confidence interval of 95%. The standard errors are calculated with the estimated standard deviation of the samples. The sample sizes were 6 and 5, for the SFRS-N and the SFRS respectively. This data shows that the addition of natural hemp-based fibre did not seem to have a negative impact on the flexural tensile strength of the concrete, as it was expected. The Fig. 5 presents the 3PBT Load-CMOD curves of the sprayed panels for the SFRS-N (Fig. 5A) and the SFRS (Fig. 5B).

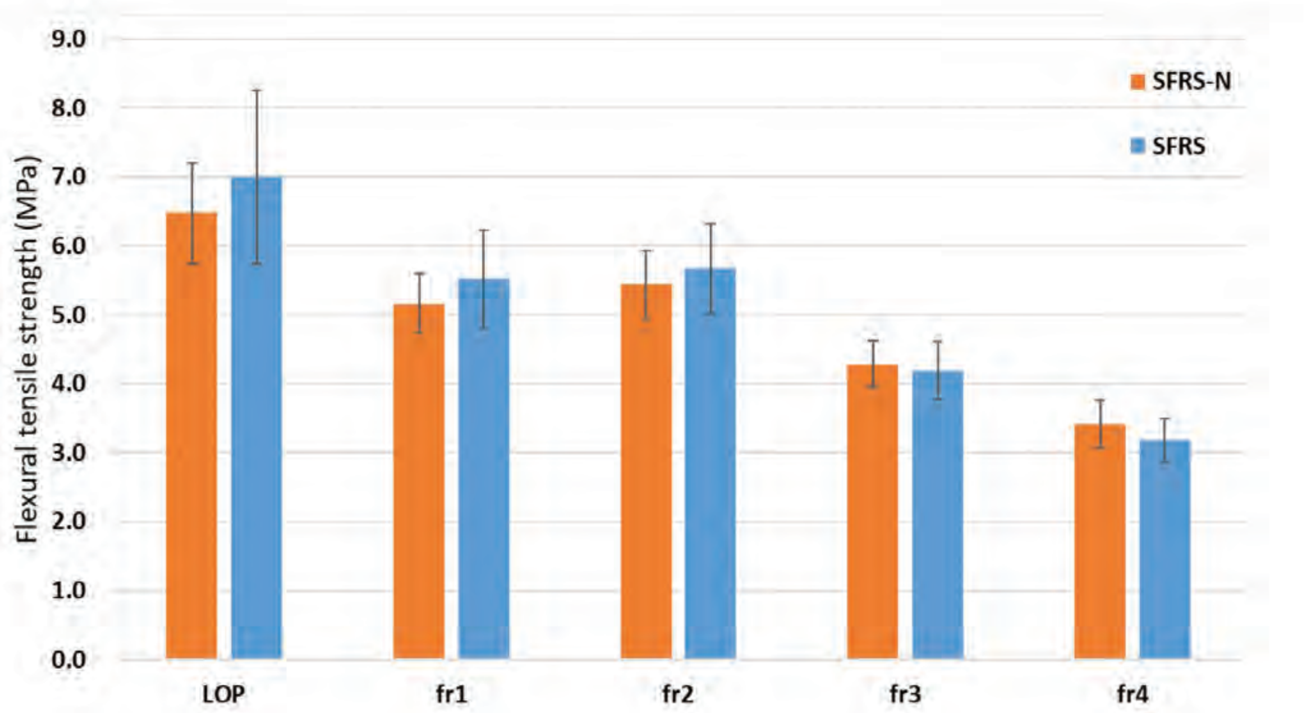


Fig. 4: LOP, flexural tensile strength and residual tensile strength of SFRS-N and SFRS (note: the error bars correspond to the standard error, for a confidence interval of 95%)

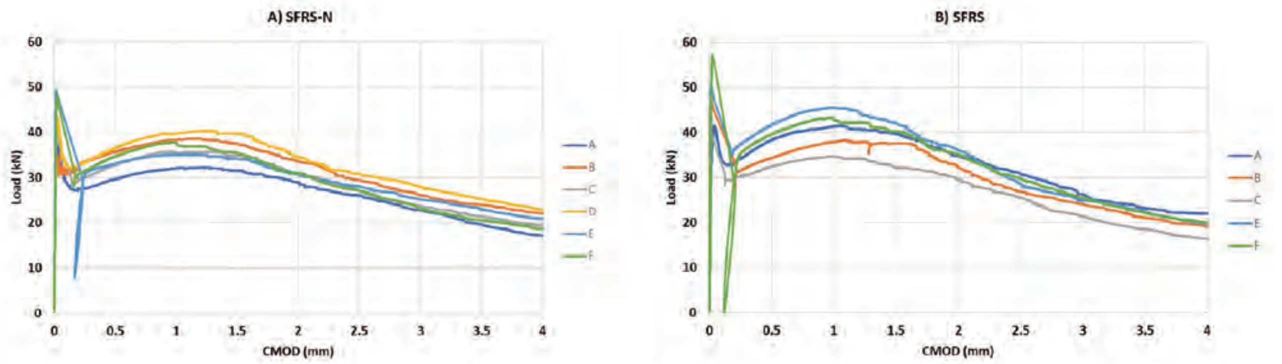


Fig. 5: 3PBT Load-CMOD curves of six sprayed panels for: A) SFRS-N and B) SFRS

Conclusion

The objective of this project was to evaluate the performance of a natural fibre produced by *NRF* incorporated in a steel fibre-reinforced wet-mix shotcrete. Overall, the pumping, the spraying, and the testing phases were conducted without any difficulties. The study has demonstrated that the natural fibre has the potential to reduce the rebound of a fibre-reinforced wet-mix shotcrete by almost 25%, which could be due to the increased cohesion of the material, and by the fact that the natural fibre absorbs a portion of the free water. In a previous study conducted at Université Laval, Gagnon and Jolin (2019) found that the fresh concrete properties (i.e., built-up thickness and finishing ability) were improved by the addition of the natural fibre, consistent with Morgan et al (2017) observations on a natural hemp-based fibre. Moreover, the natural fibre does not influence the compressive strength or the flexural tensile strength of the hardened concrete, and the coefficient of variation on residual strength is quite low with this testing (around 10 % for both mixes). Considering the significant potential for rebound reduction and improved built-up thickness, the natural fibre shows great promise when added to a steel fibre-reinforced wet-mix shotcrete for most applications, such as shotcrete support for tunnels or mines.

ACKNOWLEDGMENTS

The authors would like to thank *NRF*, who provided the natural fibre used in this study, *Bekaert Underground Solutions*, who provided the *Dramix 4D 65/35 BG* steel fibre and finally the *Centre de recherche sur les infrastructures en béton* (CRIB) for concrete laboratory at *Université Laval.*

REFERENCES

1. ACI Committee 506, "Guide to shotcrete (ACI PRC-506-16)". American Concrete Institute, Farmington Hills, MI, 2016, 52 pp.

2. ACI CPP660.1-21. 2020, "Certification Policies for Shotcrete Nozzleman and Shotcrete Nozzleman-In-Training". American Concrete Institute Farmington Hills, MI, 2016, 36 pp.

3. Gagnon, A. and Jolin, M., "Evaluating the Influence of Hemp-Based Natural Fibres on the Performance of Steel Fibre Reinforced Shotcrete". Université Laval, Quebec City, Qc, 2019, 5 pp.

4. Morgan, D. R., Zhang, L. J. and Pildysh, M. (2017). "New Hemp-Based Fibre Enhances Wet-Mix Shotcrete Performance". Shotcrete Magazine, Spring 2017, 36-45 pp.

5. Natural Reinforce. (n.a.). "Hydrophilic & Natural Fibers". [data sheet]. Hayway, CA: Natural Reinforce.

***Jean-Benoît Darveau** is a Research Engineer at the Centre de recherche sur les infrastructures en béton (CRIB) at Université Laval, Quebec City, Qc, Canada. He received his bachelor's degree in geological engineering in 2015, and his MSc in earth sciences on concrete durability from Université Laval in 2021. He started his career in 2019 as a Research Engineer in the shotcrete laboratory at CRIB. He has been involved in many shotcrete projects, from the material quality control to the adaptation to shotcrete of concrete standardized testing, with some work in the improvement of shotcrete equipment as well. He is a member of the American Concrete Institute (ACI), a Supplemental Examiner in the Shotcrete Nozzleman Certification CP-60 and Adhesive Anchor Installer Certification CP-80 programs, and now Scholarship Coordinator for the ACI-Eastern Quebec and Ontario Chapter.*

***Marc Jolin**, FACI, is a Full Professor in the Department of Civil and Water Engineering at Université Laval. He received his PhD from the University of British Columbia, Vancouver, BC, Canada, in 1999. An active member of Centre de Recherche sur les Infrastructures en Béton (CRIB), he is currently involved in projects on shotcrete automation, rebound reduction, and rheology of fresh shotcrete. Jolin is an ASA member; an ACI Examiner for Shotcrete Nozzleman Certification (wet- and dry-mix processes); Chair of ACI Committee C661, Shotcrete Inspector Certification; and member of ACI Committee 506, Shotcreting and ACI Committee C660, Shotcrete Nozzleman Certification.*

The Future for Coal Ash Supply

By Thomas H. Adams, Executive Director, American Coal Ash Association

Fig. 1: Wynah Station in Georgetown, South Carolina

Since the founding of the American Coal Ash Association (ACAA) in 1968, the association has dedicated itself to encouraging the beneficial use of fly ash, bottom ash, boiler slag, and, more recently, flue gas desulfurization (FGD) gypsum. Collectively, these materials are described as "coal combustion products (CCP)" as this term stresses the monetary value of the products when placed into a beneficial use rather than diverted to disposal in landfills or ash ponds.

Beneficial use of CCP, commonly called 'recycling,' keeps these materials out of landfills and storage ponds by using them to produce and improve a wide variety of products including concrete, portland cement, wallboard and other gypsum panel products, roofing shingles, and soil amendments for farms. The use of CCP as an aggregate avoids the mining of virgin aggregate sources for geotechnical applications. CCP use often provides a more sustainable solution to market needs while improving the value of finished products.

The question that we are asked most frequently – by far – is, "what is the outlook for future supplies of fly ash?" Demand for fly ash and other supplementary cementitious materials (SCM) has been increasing steadily for many years. Research and field experience over several decades have changed fly ash from being regarded as a cheap filler to a strategic tool for concrete producers in meeting increasing demand for improved durability. In recent years, the available supply of fly ash has been shrinking as

Fig. 2: Montour landfill near Washington, PA

older coal-fueled power plants retired. Natural gas fueled plants took over some of the coal's market share as fracking dramatically increased gas supplies along with much lower prices for natural gas, often below the cost for using coal. In addition, anti-coal activists have put great pressure on electric utilities to stop using coal altogether in favor of renewable energy sources that are not scaled to meeting market demand. These factors have created a serious concern for architects and engineers, concrete producers, and concrete contractors who work to design and build durable, high performance concrete structures and pavements.

The CCP that has the highest value is fly ash. Fly ash use in concrete benefits concrete performance by improving handling in the plastic state and improving strength and durability in-service. Fly ash has long been regarded as the number one tool for mitigating alkali-silica reaction (ASR) and improving sulfate resistance. Class F is regarded widely as the most effective and economical solution to mitigating ASR. Again, architects and engineers are concerned about the availability of fly ash to avoid ASR or for improved sulfate resistance.

So, what is the answer to the question, "what is the outlook for future supplies of fly ash?" While we have fewer sources of fly ash from coal-fueled power plants, the answer is not quite as bleak as you might think.

Let us look first at the amount of fly ash from coal combustion. Annual production of fly ash is expected to continue to gradually to decline over the next 15 to 20 years. In 2019, the ACAA engaged the American Road and Transportation Builders Association (ARTBA) to update a forecast first done in 2015.

In the update, ARTBA reported the *best-case* scenario for the use of coal would grow about 20% from current levels. To achieve this outcome, utility companies and regulators would have to make commitments to the use of carbon capture and storage, upgrading emission controls, and

Fig. 3: Montour landfill near Washington, PA

Fig. 4: Montour landfill near Washington, PA

more efficiency in combustion systems. This is not likely to happen, but it is possible.

The *worst-case* would be a decline by about 31% over the same 20-year period. Under this scenario, the premature closing of efficient coal-fueled power plants would continue as in recent years. This action seriously endangers the stability of energy grids as seen in recent black-out and brown-out events in California and Texas. Because of these events and the energy crisis currently spreading across Europe, some regulators and utility leaders are pumping the brakes on their ambitious plans to close coal-fueled plants.

The *most likely* scenario would be a decline of about 15%. Today we are showing this model is holding up very well. We are currently producing fly ash at a level just below the most-likely scenario.

What solutions are available to the forecasted decline in fly ash supply from power plants? Some suggest we import fly ash from other countries. However, transporting large quantities of fly ash across oceans presents difficult logistical and cost problems. Significant terminal capacity on both ends of the transaction is required. Shipments must be made in large quantities up to 50,000 tons to make economic sense. The U.S. has very few large terminals on the coasts that could handle such quantities. Fly ash is a finely divided powder and must be transported in pneumatic vessels. There are a very limited number of these vessels in service today. Some imports of fly ash are reported from time-to-time. They have been very discrete transactions for very specific projects. Today, most of the CCP imported to the U.S. is bottom ash being shipped to ports in Florida for use in producing portland cement. It is not likely imports will provide much relief, if any.

"Harvesting" is an activity that is starting make a difference in some markets. Harvesting is the recovery of CCP from landfills and ponds, processing for use in cement and concrete production. Many of the ash ponds across the U.S. are closing in response to the U.S. Environmental Protection Agency (EPA) Coal Combustion Residual Rule of 2015. Some ponds are being closed-in-place. These ponds are dewatered, covered with an impermeable membrane, and covered with soil and aggregates. Some ponds have demonstrated a higher impact on ground water. These ponds are required to close-by-removal. In these cases, the pond is dewatered, the CCP is partially dried, and processed for transportation to a landfill. In some cases, the CCP can be processed for beneficial use. Harvesting on a large scale began in Georgetown, South Carolina at a power plant owned by Santee Cooper. This plant was working with the SEFA Group, an ACAA member, to beneficiate or process fly ash coming out of the plant for use in concrete. Using their patented STAR technology, SEFA thermally treated the fly ash to get a consistent 1.0% loss on ignition. Starting in 2015, this team decided to try processing fly ash harvested from a large pond on site to see if the system worked for harvested ash. Today, this plant furnishes about 150,000 tons per year to the market in the region. Even better, the STAR system processes harvested fly ash even when the power plant is not producing electricity. Consistent product delivered consistently.

Harvesting has entered its third year at a landfill in Pennsylvania. A landfill used by PPL for many years had been completely closed for 10 years when PPL and Boral Resources (now Eco Material Technologies) approached the Pennsylvania Department of Environmental Protection (PDEP) for permission to reopen the landfill and remove approximately 2 million tons of high-quality Class F fly ash. At first, the PDEP was skeptical. No one had ever asked for such permission. Eventually, PDEP agreed that this was a win-win-win proposal for the environment, the state, and the customers needing Class F fly ash.

In 2022, Duke Energy and the SEFA Group went into full-scale harvesting operations at 3 sites in North Carolina. Each of these sites have ponds subject to closure-by-removal. At each site, Duke Energy is required to process a minimum of 300,000 tons of fly ash suitable for use in concrete mixtures per year. The requirement was the result of action by the North Carolina legislature and the governor as part of the state's coal ash management regulations.

Just 2 months ago, Georgia Power, a subsidiary of Southern Company, announced a harvesting program created in cooperation with the State of Georgia. When in full operation expected in about 1 to 2 years, Georgia Power will have approximately 900,000 tons of concrete-grade fly ash per year available for fly ash users in that region.

More harvesting is ongoing in the western U.S. and more states are considering regulations which will require utility companies to process harvested coal ash for beneficial use. In 2022, ACAA expects that harvesting coal ash will increase the amount of coal ash available to regional concrete markets by as much as 2,000,000 tons!

It is important to remember that harvesting is expensive. Costs depend on the amount and type of processing needed. In addition, most of the ponds undergoing closure-by-removal are very large with several million tons of coal ash being stored in them. Removal of the coal ash from those ponds will take 10 to 20 years. This makes harvesting a long-term commitment with significant capital expenditures required.

Additional relief is on the horizon with changes in specifications for fly ash use in concrete. ASTM International Committee C09 is balloting changes to the ASTM C618, Standard Specification for Fly Ash and Natural Pozzolan Use in Concrete, to recognize harvested ash and bottom ash use in concrete mixtures. If approved, this will provide support to efforts to expand use of harvested ash. Bottom ash will most likely have to be ground to meet the fineness requirement in the proposed revisions. Under the revisions proposed, the term "fly ash" will be replaced with "coal ash." The revisions will be a large step forward in making C618 a performance specification rather than a prescriptive specification.

Other specification activity is addressing the interest in combining coal ash with other SCMs such as natural pozzolans and slag cement. Such blends are already being marketed by coal ash marketers in some regions of the U.S. Additional work is ongoing to create a standard test to measure pozzolanic reactivity. With numerous products being brought forth to fill the gap between SCM demand and supply, specifiers and users need reliable tests to evaluate these products.

The cement and concrete industries are advancing toward achieving carbon neutral concrete mixtures. A big part of that effort is increased use of SCMs. Fly ash, soon to be referred to as coal ash, is, by far, still the #1 SCM by volume. While coal-fueled power plants will continue to be challenged to maintain a presence in our energy mix, commitments to harvesting some of the 2.5 billion tons of CCP in disposal units around the U.S. will help meet the engineering and environmental demands of today's markets.

Thomas H. Adams *has served as executive director of the American Coal Ash Association since 2009. Prior to joining ACAA, Mr. Adams was on the staff of the American Concrete Institute, the American Shotcrete Association, and the Michigan Concrete Association. He has over 30 years of experience in the ready mixed concrete industry in sales and technical service management positions. Thomas Adams is a fellow of the American Concrete Institute. He is active on several technical committees in ACI and ASTM International.*

Manufactured Sand: The Natural Solution

By Joey Bell

Sand is the most extracted solid material in the world, the second most used global resource behind water, and used in every construction project on earth. It is also one of the most critical ingredients in concrete production.

The world uses around fifty billion tons of sand annually, twice the amount of sediment moved by rivers. Damming of rivers in the past century has dramatically decreased natural sand production. In 2012, 26 billion tons of sand went into making concrete alone. Due to sprawling urbanization around many cities in the United States and other countries, concrete is in high demand, and sand extracting occurs far more quickly than it renews.

Concrete production is not alone in significant sand usage. Glass manufacturing and oil well fracking use tremendous amounts of sand. The total U.S. sand production used by the fracking industry surged from only 5% in 2003 to 72% in 2014.

This massive increase in demand for concrete sand has led to price appreciation. Some reports have costs in 2022 skyrocketing to 185% higher than in 2021.

High demand has also led quality to decrease. Sand suppliers sometimes scrape the bottom of the barrel to get their product out to customers. Organic impurities in natural sand like silt and clay can wreak havoc on concrete's air content and hardened properties that can cause unwanted cracking. Additional processing can significantly reduce impurities, but these extra steps raise costs and slow production.

Rising transportation costs also put pressure on concrete producers. Many producers pay more for the cost of delivery than the actual sand. In addition, sand pits in remote locations like dried-up riverbeds have higher transportation costs even before factoring in record-high fuel prices.

PROBLEMS WITH OTHER SOURCES

Desert sand: Particles subjected to wind erosion for countless millennia are much too round and often too delicate for concrete production. **Sea sand:** Needs washing, or the salt contained throughout will rust steel reinforcement.

A MORE VIABLE SOLUTION

Manufactured sand is more available than a desert or shoreline. It is often a byproduct of rock crushing, and some quarries make it a point to produce manufactured sand that meets ASTM C33.

A quick google search on a middle Tennessee location yielded no less than 25 quarries within 100 mi (160 km). Only a fraction of those locations would need to produce manufactured sand for a concrete producer to have several viable options, providing a much better supply prospect than 1-2 options of costly, inconsistent, natural sand that could run out any day.

THE MANUFACTURED SAND STIGMA

Manufactured sand is not some secret that has disappeared for decades. On the contrary, many concrete producers know its availability and potential cost savings. However, often when manufactured sand comes up in conversation, eyebrows furrow, heads start shaking, and repressed memories of jobsite nightmares like blocked pumps and profanity-screaming finishers come surging back.

Manufactured sand is known for a couple of disadvantages.

Workability Issues: Manufactured sand is angular and may become too angular due to specific rock-crushing processes. *Desired process:* Manufactured sand crushed with a jaw crusher is ideal because it is often more cubical and uniform, which is excellent for particle packing in concrete. These smoother angles make pumping and finishing easier with less cement paste needed. *Less desired process:* Manufactured sand crushed with a rotary or conical crusher tends to be irregular in shape and may produce more "shard-like" flaky, elongated particles. Concrete can use these aggregates, but the mix design needs modification to compensate for common performance issues like pumpability and finishability. Due to their added surface area, the odd-shaped particles require more cement paste in the concrete to pump. During

the finishing process on the concrete slab, those sharp particles "tear" the surface of the concrete when trowel finishing. Added cement paste will undoubtedly help but adding more of the most expensive material in the formula negates the cost-benefit of manufactured sand.

Micro Fines: Micro fines classify as particles finer than a No. 200 sieve. Manufactured sand can have an abundance of these micro fines. Micro fines can increase the water demand in concrete, thus lowering its strength. They can also reduce workability and retention of workability even when a high-range water reducer (HRWR) is in the mix design. The added fines' surface area requires more cement paste to maintain pumpability and finishability.

Supply: Finding a quarry that can keep up with potential market demand could pose an issue for a concrete producer. Manufactured sand is often a byproduct of rock crushing, and sometimes a quarry will not produce enough to supply a concrete plant. For example, a cubic yard of 3000 psi (21 MPa) concrete mix could include around 1200 lb (540 kg) of sand. If that plant is doing 200 yards of that mix every day for five days a week, that is 600 tons (544 tonnes) of sand a week. It might take a substantial quarry to supply that much "by-product" to multiple concrete plants.

SOLUTIONS TO THE MANUFACTURED SAND STIGMA

Advancements in admixture technology have brought several solutions for manufactured sand issues.

Increased Cement Paste: Some concrete producers have increased the percentage of manufactured sand in their formulas by increasing the cement paste. For these producers, the benefit of continuously supplying their customers outweighs the costs associated with added cement content.

Chemical Solutions: Some admixtures on the market today catered to aggregate producers rather than concrete producers. They selectively react with clay contaminants to eliminate the negative effect of swelling clays in concrete. These admixtures and the aggregates blend at the quarry.

Several chemical companies have modified conventional concrete admixtures like water reducers, air-entrainment, and viscosity modifying admixtures to help combat manufactured sand performance.

Mineral Solutions: A drawback of chemical admixtures is that they break down over time during mixing and delivery. This issue has led some concrete producers to mineral admixtures and nano clays since a mineral admixture will not break down over time. It will continue to work as usual as the concrete sets.

Palygorskite mineral admixture is a natural suspension agent for almost any high-solids mixture and improves suspension and stabilization. As a result, paints, coatings, mining, fertilizer suspensions, oil & gas, and many other industrial applications have used the mineral for decades. The tiny rod-shaped particles have a typical length of two microns and a circumference of thirty nanometers.

At rest, electrically charged palygorskite particles form a 3-dimensional lattice structure that separates and suspends other particles preventing segregation and enabling a homogeneous mixture. In motion, the lattice structure quickly breaks, allowing the mixture to flow freely. This process results in lower viscosity and improved flowability and pumpability. The rate of 'thixotropic recovery' is instantaneous. The lattice structure returns to a stable homogeneous suspension immediately after the shear stops.

In the past decade, palygorskite's thixotropic properties have found their place in the concrete world. It is unaffected by freeze/thaw, is pH tolerant, and can cooperate with almost any admixture on the market. As a result, palygorskite is a reliable solution to increasing manufactured sand percentage in concrete mixes.

Palygorskite works in concrete by maintaining or improving the workability and flow of the high-solids mixture. In addition, the tiny particles create a lattice structure throughout the cement paste, making it more robust and creamier. This enhanced paste content advantage is also evident in high-percentage manufactured sand formulations.

CONCLUSION

Natural sand supply has no predicted increase any time soon. Therefore concrete producers need to get ahead of the curve by utilizing more manufactured sand today, or they risk scrambling to fill customer orders at a higher price.

Experience with manufactured sand has scarred many producers in the industry to the point that they will not even entertain the possibility of using it ever again. Nevertheless, growing concerns with natural sand availability and price have driven the concrete world to explore other avenues of fine aggregate.

Some have "fixed" their manufactured sand mixes the old-fashioned way by adding another sack of cement to the design to keep customers supplied. Others have turned to admixture companies for assistance with new and innovative chemical and mineral additives.

The industry must adopt these newer technologies to calm its fears of past experiences and keep up with growing demand.

Joey Bell, Business Development Manager, Active Minerals International, grew up on a farm in Tennessee and received his BS in Concrete Industry Management from Middle Tennessee State University, Murfreesboro, TN. Bell travels the world developing new customers through technical support, product demonstrations, and field sales support for the Acti-Gel® 208 concrete additive. Along with shotcrete, his role at Active Minerals has furthered his knowledge in other applications, such as lightweight concrete, precast, slipform paving, RCC, and concrete block. Bell is Active Minerals' corporate member representative for ASA and also a member of the Pool and Recreational Shotcrete Committee.

Shotcrete Design Mix – Using Superabsorbant Polymers

By Jose Juan Flores Martinez, Geological Engineer

BACKGROUND

Shotcrete is one of the variants for construction that has grown widely in recent years due to its versatility, it is used in many works, among them, slopes, mines, pools, walls of irregular shapes, etc. The topic of this article lies in the discussion about the mix designs that are mainly used in the wet method and the improvements that have been achieved by using Superabsorbent Polymers (SAP) in the design of these mixes.

Unlike conventional concrete whose designs are made mainly based on compressive strength, shotcrete designs are made thinking more about the rheology of the material to obtain better properties such as flow, cohesiveness, adherence, rebound, or ease of pumping, among others, or to obtain compressive strength at an early age. Due to the foregoing, these designs are generally based on criteria that normally point towards greater consumption of fines particles, whether they are cement when seeking to achieve high strength at early ages and/or with the use of supplementary cement. These mixtures are also loaded with fine aggregates and some coarse aggregates. Therefore, additives used in these designs also focus on improving the rheology of these mixes. The use of SAP provides an alternative means to meet the design criteria, achieving significant reductions in the amounts of fines materials, mainly of cement, which makes shotcrete a better, cost-effective solution compared to traditional construction methods where significant formwork is initially required to shape the element to be manufactured. Shotcrete requires little to no formwork in its placement. Some of the advantages that the use of SAP can provide in shotcrete designs are reviewed below.

CONSUMPTION OF CEMENT AND/OR SUPPLEMENTARY CEMENTITIOUS MATERIALS

Most concrete design criteria are based on the compressive strength that the concrete must meet either at 28 days or some early age. According to this criterion in shotcrete, there are practically no mechanical strength problems because the amount of cement is normally higher, satisfying the rheological properties of the material first. This leads to high consumption of cement, which consequently results in expensive mixtures or mixtures where all this cement is not properly used and/or causing current concern over very high CO2 footprints. In many places, this is compensated with the use of supplementary cement such as fly ash or microsilica, although, in addition to rheology, these materials are used to improve the durability of the concrete.

In some regions, these types of materials are not available or are located very far from the area where they are produced, which increases production costs. To achieve the same rheology, the use of SAP can generate the same or better rheological effects. SAP converts part of the liquid water into a colloidal or gel state with rheological properties that are maximized in the gunning process, with even better characteristics than those achieved with cement or supplementary cementitious materials.

COMPRESSIVE STRENGTH

Regarding the criterion to obtain compressive strength at an early age, SAP in combination with accelerating additives, can be used to obtain this performance, with the use of special cements such as sulphoaluminate. This has been demonstrated in shotcrete mix designs in the mine, below grade or parking lot markets, where the original designs were able to reduce up to 100 kilos of cement per m^3 from the original design (as shown in the following table).

	Conventional Shotcrete	SAP Shotcrete
Gravel sand Ratio	0.4	1.0
Cement Consumption	≥ 420 kg/cm^3	This application only needed 320 kg/m^3
Rebound loss	Between 5 to 12%	Between 0 to2%
Slump	High	Normal, what is necessary for pumping
Adhesion to the substrate	Regular	Excellent
Fine materials additions	Up to 30% of fine materials (microsilica)	No fine material used
Fibers	With synthetic macro fiber	With synthetic macro fiber
Pumping	With the use of the fibers, the fiber is plugged and secreted	Easy pumping keeps the fiber very well integrated into the concrete

AGGREGATES

Although it is known that the best properties of concrete, such as mechanical strength, flexural strength, modulus, or abrasion resistance, depend mainly on the coarse aggregate; conventionally, regardless of the design criteria used, the aggregates in shotcrete design tend to lean towards the fine side. Coarse aggregates, limiting its maximum size to ½ in. or 3/8 in. (13 or 10 mm), is used much less frequently. This is again due to the rheology needs of the mix, since designs with a greater amount of coarse aggregate must

Mezcla de Diseño de Hormigón Proyectado – Uso de Polímeros Superabsorbentes

Por Jose Juan Flores Martinez, Ingeniero Geólogo

ANTECEDENTES

Shotcrete es una de las variantes para la construcción que ha crecido ampliamente en los últimos años debido a su versatilidad, se utiliza en muchas obras, entre ellas, pendientes, minas, piscinas, paredes de formas irregulares, etc. El tema de este trabajo reside en la discusión sobre los diseños de mezcla que se utilizan principalmente en el método húmedo y las mejoras que se han logrado mediante el uso de polímeros superabsorbentes (SAP) en el diseño de estas mezclas.

A diferencia del hormigón convencional cuyos diseños se basan principalmente en la fuerza compresiva, los diseños de hormigón se hacen pensando más en la reología del material para obtener mejores propiedades como flujo, cohesión, adherencia, rebote, o facilidad de bombeo, entre otros, o para obtener fuerza compresiva a una edad temprana. Debido a lo anterior, estos diseños se basan generalmente en criterios que normalmente apuntan hacia un mayor consumo de partículas finas, ya sea cemento cuando se busca lograr una alta resistencia a edades tempranas y/o con el uso de cemento suplementario. Estas mezclas también están cargadas con agregados finos y algunos agregados gruesos. Por lo tanto, los aditivos utilizados en estos diseños también se centran en mejorar la reología de estas mezclas. El uso de SAP proporciona un medio alternativo para cumplir los criterios de diseño, logrando reducciones significativas en las cantidades de materiales finos, principalmente de cemento, lo que convierte al shotcrete en una solución mejor y rentable en comparación con los métodos de construcción tradicionales, donde inicialmente se requiere encofrado importante para dar forma al elemento que se va a fabricar. El hormigón proyectado requiere poco o ningún encofrado en su colocación. Algunas de las ventajas que el uso de SAP puede proporcionar en diseños de hormigón proyectado se revisan a continuación.

CONSUMO DE CEMENTO Y/O MATERIALES CEMENTOSOS SUPLEMENTARIOS

La mayoría de los criterios de diseño del hormigón se basan en la resistencia compresiva que el hormigón debe cumplir ya sea a los 28 días o a una edad temprana. Según este criterio en el shotcrete, no hay prácticamente ningún problema mecánico de la fuerza porque la cantidad de cemento es normalmente más alta, satisfaciendo primero las propiedades reológicas del material. Esto conduce a un alto consumo de cemento, lo que da como resultado mezclas o mezclas costosas en las que todo este cemento no se utiliza correctamente y/o causa preocupación por las huellas de CO2 muy altas. En muchos lugares, esto se compensa con el uso de cemento suplementario como cenizas volantes o microsílice, aunque, además de la reología, estos materiales se utilizan para mejorar la durabilidad del hormigón.

En algunas regiones, estos tipos de materiales no están disponibles o se encuentran muy lejos de la zona donde se producen, lo que aumenta los costes de producción. Para lograr la misma reología, el uso de SAP puede generar los mismos o mejores efectos reológicos. La SAP convierte parte del agua líquida en un estado coloidal o en gel con propiedades reológicas que se maximizan en el proceso de pistoleo, con mejores características que las obtenidas con cemento o materiales cementosos suplementarios.

RESISTENCIA A LA COMPRESSION

En cuanto al criterio para obtener resistencia a la compresión a una edad temprana, la savia en combinación con aditivos acelerantes, puede ser utilizada para obtener este rendimiento, con el uso de cementos especiales como el sulfoaluminato. Esto se ha demostrado en diseños de mezclas de hormigón en la mina, por debajo de la ley o en los mercados de aparcamientos, donde los diseños originales pudieron reducir hasta 100 kilos de cemento por m^3 del diseño original (como se muestra en la siguiente tabla).

	Concreto Lanzado convencional	Concreto Lanzado con SAP
Relación Grava /Arena	0.4	1.0
Consumos de cemento	≥ a 420 kg/m^3	Para esta aplicación se uso 320 kg/m^3
% pérdida por rebote	Entre 5 a 12%	0 a 2%
Revenimientos	Altos	Normal lo necesario para el bombeo
Adherencia al sustrato	Regular	Muy buena
Adiciones de finos	Hasta 30% de finos (microsilica)	Sin uso de finos
Fibras	Con macrofibra sintética	Con macrofibra sintética
Bombeo	Con el uso de las fibras se taponea y se segrega la fibra	Fácil bombeo mantiene muy bien integrada la fibra en el concreto

remain pumpable. Larger aggregates pose problems of segregation, pumping, cohesiveness, adhesion, and rebound. Therefore, shotcrete designs have a low gravel/sand ratio with values ranging between 0.40 and a maximum of 0.60. Through the SAP, gravel/sand ratios of 1.0 to 1.2 have been achieved with a maximum size of 3/4 in. (19 mm) which allows better mechanical properties to be obtained in shotcrete. Another property of the aggregate that affects the characteristics of the shotcrete process is the shape factor. Crushed aggregates is growing in popularity, but they do not always have the best shape factor since they usually contain significant amounts of elongated and flat shapes. This characteristic also affects the rheological properties such as pumpability, cohesiveness, adherence and rebound. These deficiencies in the mixture usually are corrected again with additional cement. The use of the SAP corrects these deficiencies of the aggregates with greater efficiency and at a much lower cost than correction via cement.

One of the variants less used in the shotcrete process is the use of low volumetric weight concretes. This is due, in part, to the same high consumption of cement, that automatically gives it a high density, and the use of light aggregates which, whether naturally or artificially, tend to segregate, thus a correct integration is not achieved in this type of concrete. The problem of segregation also becomes noticeable in shotcrete that uses synthetic fiber which, even with high amounts of cement and/or additional binders, do not manage to retain the fiber, therefore much of this fiber is lost in the rebound and/or due to the same segregation caused by the pumping equipment. The use of the SAP significantly reduces this problem, leaving the fiber in the concrete mass, eliminating its loss either by rebound or by the action of pumping, the same thing happens with lightweight aggregates, which encourages the use of light weight shotcrete in works where this quality is required.

ADDITIVES

Normally, water-reducer, plasticizer, and superplasticizer additives are most commonly used in shotcrete when seeking to achieve compressive strength at an early age. Accelerants are also used. Regarding the first group, they are essential to achieve the necessary slump for a pumpable concrete. Sometimes superplasticizers are used to introduce air into the mix or they can be added with an air entrainer additive. Although the air-entrained can help the rheology of the mix, as is well known, the inclusion of air has repercussions. Compressive strength is decreased if good control over its percentage in the mix is not achieved. On the other hand, part of this percentage of air is lost or collapses during the shotcrete process due to the pressure exerted by the equipment on the material. SAP improves the rheological properties of the mix since it functions to bring part of the liquid water in the mix to a colloidal state, achieving the rheological properties sought in the material. Additionally, by releasing this moisture in a controlled manner, it generates internal curing at the mixture which allows better hydration of Portland cement and a reduction in cracking by dry shrinkage.

HOW SUPERABSORBENT POLYMER WORKS

The main function of the SAP is to convert part of the liquid water in the mix design into a differentiated colloidal state in three stages: First, to absorb and convert the liquid water into a gel. Second, to maintain this consistency for a period of time so SAP can print rheological properties to the mixture, generating a pasty appearance, with better workability, pumpability, cohesiveness, adherence among other properties that are used in the plastic state. Third, the Polymer releases this gel back to the liquid state (at the level of pore solution), where it can cause internal curing of concrete.

MINING PROJECT EXAMPLE

Fig. 1: Synthetic fiber floating on the surface of liquid water.

Fig. 2: Synthetic fiber suspended without floating to the surface with gel water (sample water with SAP)

Fig. 3: Suspended steel fiber without settling at the bottom of the container with gel-water.

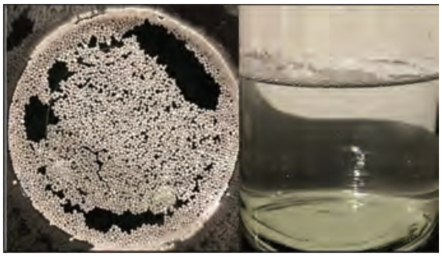


Fig. 4: Polystyrene microbeads float on the surface of liquid water without being able to integrate into the volume of the container.

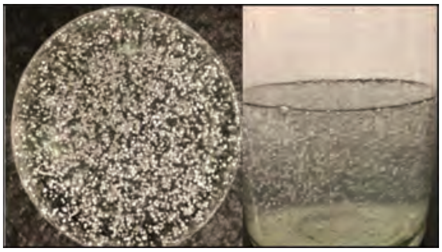


Fig. 5: Polystyrene microbeads are integrated into the entire volume of gel without agglomerating or floating on the surface.

de flexión, el módulo, o la resistencia a la abrasión, dependen principalmente del agregado grueso; convencionalmente, independientemente de los criterios de diseño utilizados, los agregados en el diseño de shotcrete tienden a inclinarse hacia el lado fino. Agregados gruesos, limitando su tamaño máximo a pulg. o 3/8 pulg., se utiliza con mucha menos frecuencia. Esto se debe de nuevo a las necesidades reológicas de la mezcla, ya que los diseños con una mayor cantidad de agregado grueso deben permanecer bombeables, problemas de segregación, bombeo, cohesividad, adhesión, y el repunte se encuentra entre los desafíos a los que se enfrenta. Por lo tanto, los diseños de hormigón tienen una baja relación grava/arena con valores que oscilan entre 0,40 y un máximo de 0,60. TítuloA continuación se han alcanzado las proporciones de savia, grava/arena de 1,0 a 1,2 con un tamaño máximo de 3/4 pulg. lo que permite obtener mejores propiedades mecánicas en el shotcrete. Otra propiedad del agregado que afecta a las características del proceso de shotcrete es el factor de forma. Los agregados aplastados están creciendo en renombre, pero no tienen siempre el mejor factor de la forma puesto que contienen generalmente cantidades significativas de formas alargadas y planas. Esta característica también afecta a las propiedades reológicas como la bombeabilidad, la cohesión, la adherencia y el rebote. Estas deficiencias en la mezcla se corrigen generalmente otra vez con el cemento adicional. El uso de la savia corrige estas deficiencias de los agregados con mayor eficiencia y a un costo mucho menor que la corrección a través del cemento.

Una de las variantes menos utilizadas en el proceso de shotcrete es el uso de concreto de bajo peso volumétrico. Esto se debe, en parte, al mismo alto consumo de cemento, que automáticamente le da una alta densidad, y al uso de agregados ligeros que, ya sea natural o artificialmente, tienden a segregar, por lo que no se logra una correcta integración en este tipo de hormigón. El problema de la segregación también se hace evidente en el hormigón que utiliza fibra sintética que, incluso con grandes cantidades de cemento y/o aglutinantes adicionales, no consigue retener la fibra, por lo tanto, gran parte de esta fibra se pierde en el rebote y/o debido a la misma segregación causada por el equipo de bombeo. El uso de la savia reduce significativamente este problema, dejando la fibra en la masa de hormigón, eliminando su pérdida por rebote o por acción de bombeo, lo mismo sucede con los agregados ligeros, lo que fomenta el uso de un ligero zotcrete en obras donde se requiere esta calidad.

ADITIVOS

Normalmente, los aditivos reductores de agua, plastificantes y superplastificantes se utilizan más comúnmente en el hormigón cuando se busca lograr la resistencia a la compresión a una edad temprana. También se utilizan acelerantes. En cuanto al primer grupo, son esenciales para lograr la depresión necesaria para un hormigón bombeable. A veces se utilizan superplastificantes para introducir aire en la mezcla o se pueden añadir con un aditivo de aire absorbente. Aunque el aire atrapado puede ayudar a la reología de la mezcla, como es bien sabido, la inclusión de aire tiene repercusiones. La resistencia a la compresión disminuye si no se logra un buen control sobre su porcentaje en la mezcla. Por otro lado, parte de este porcentaje de aire se pierde o se colapsa durante el proceso de shotcrete debido a la presión ejercida por el equipo sobre el material. La SAP mejora las propiedades reológicas de la mezcla ya que funciona para llevar parte del agua líquida que la mezcla a un estado coloidal, logrando las propiedades reológicas buscadas en el material. Adicionalmente, liberando esta humedad de una manera controlada, genera curado interno en la mezcla que permite una mejor hidratación del cemento Portland y una reducción en el agrietamiento por encogimiento seco.

CÓMO FUNCIONA EL POLÍMERO SUPERABSORBENTE

La función principal de la savia es convertir parte del agua líquida en el diseño de la mezcla en un estado coloidal diferenciado en tres etapas: Primero, absorber y convertir el agua líquida en gel. En segundo lugar, mantener esta consistencia durante un período de tiempo para que la savia pueda imprimir propiedades reológicas en la mezcla, generando un aspecto pastoso, con mejor trabajabilidad, bombeabilidad, cohesividad, adherencia entre otras propiedades que se utilizan en el estado plástico. En tercer lugar, el polímero libera este gel de nuevo al estado líquido (a nivel de la solución de poro), donde puede causar el curado interno del hormigón.

Fig. 1: Fibra sintética flotando en la superficie del agua líquida.

Fig. 2: Fibra sintética suspendida sin flotar a la superficie con agua en gel (muestra de agua con SAP)

Fig. 3: Fibra de acero suspendida sin depositar en el fondo del recipiente con gel-agua.

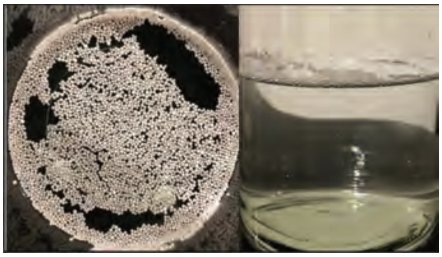


Fig. 4: Las microperlas de poliestireno flotan en la superficie del agua líquida sin poder integrarse en el volumen del recipiente.

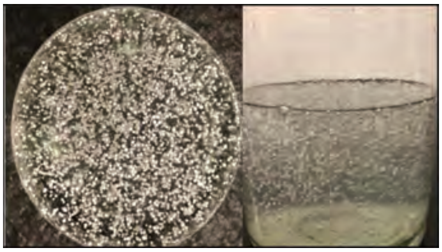


Fig. 5: Las microperlas de poliestireno se integran en todo el volumen de gel sin aglomerarse ni flotar en la superficie.

The addition of the SAP for a shotcrete mix design used on a mining project was able to reduce rebound loss up to 1.6% compared to the original design which varied between 10 to 12%. The mix design was optimized by reducing the content of cement by 100 kg, and the gravel/sand ratio was increased from 0.4 to 1.0 with ½ in. gravel. Loss of the microfiber was greatly reduced since, in the original design, a large part of this fiber was lost in the rebound. This process also reduced the risk of clogging the pumps that removed water out of the mine, by reducing the amount of rebounded material in drainage.

Fig. 6: The loose fiber in the mine drains due to rebound from the shotcrete process (between 10 to 12%).

Fig. 7: Appearance of the concrete designed with the Superabsorbent Polymer (SAP) with fiber included. (only a 1.6% loss).

Fig. 8: Slump test and appearance of the original concrete with fiber included. With values of 10 to 12% rebound and fiber loss.

Fig. 9: Slump test and concrete appearance using the Superabsorbent Polymer (SAP) with fiber included. With a value of 1.6% rebound and fiber loss.

Other advantages observed in shotcrete where the SAP is used include:

- Surfaces of vertical elements or filling irregular shapes, (elements where appropriate curing is very difficult to apply). Integrating SAP in the mix imprints a controlled release of moisture, giving it the internal curing necessary for the hydration of Portland cement, reducing the risk of cracks formed in the plastic state, and reducing drying shrinkage caused by the number of fine particles it contains.
- The shotcrete process is carried out in favorable conditions with less dust since part of the water is in the form of a gel.
- The handling and dosage of the SAP is simple since they are smaller quantities of only a few grams per cubic meter of concrete
- It is a technology compatible with most of the additives used in the shotcrete industry and has an excellent correlation with polycarboxylate-type superplasticizers.
- Includes a high degree of cohesiveness and adhesion to the mix
- Reduces the percentage of loss in overhead applications
- Reduction of rebound implies an improvement in volumetric performance and time savings in execution since it is not necessary to cover areas with multiple passes as thicker layers are possible with fewer deformations.

Fig. 10: Shotcrete designed with Superabsorbent Polymer (SAP) with excellent workability, pumpability, and adhesion with the substrate in a very clean with no dust or breeze with virtually no bounce.

Conclusions

The use of the SAP has shown to generate essential benefits to the shotcrete design, mainly in its rheological properties, where traditionally, corrections were made through the fines of cement and/or supplementary cementitious materials, the latter being not always available or expensive to get. The properties it improves in mix designs include: higher gravel/sand ratios, avoids high consumption of fines to obtain rheological properties, improves workability, pumpability, adherence to the substrate, reduces rebound loss, improves cohesiveness, avoids loss of light materials used in the mixes, e.g. synthetic fibers and/or the use of light weight aggregates, does not increase air into the concrete and is compatible with most of the additives used in shotcrete industry. By releasing moisture in a controlled manner, it generates internal curing that reduces the risk of cracking and favors the hydration of Portland cement in elements where it is difficult to apply conventional curing processes.

JOSÉ JUAN FLORES MARTÍNEZ, *Geological engineer graduated from Facultad de Ingenieria de la Universidad Nacional Autonoma de Mexico. He is currently director of the Innovation and Solution in Polymers company and he worked at Centro de Tecnologia Cemento y Concreto of the CEMEX Group. With over 25 years of experience in petrographic analysis, with application in solving aggregate quality problems for concrete and hardened concrete. In addition to being a professor at the Facultad de Ingenieria, UNAM teaching the subjects of Petrology, Sedimentary Petrology and Metamorphic Petrology, he has also written and published several articles in national and international journals and conferences.*

EJEMPLO DE CÓMO USAR EL SHOTCRETE EN UNA MINA

La adición de la savia para un diseño de Shotcrete de mina fue capaz de reducir la pérdida de rebote hasta un 1,6% comparado con el diseño original que varió entre un 10 a un 12%. El diseño de la mezcla se optimizó reduciendo el contenido de cemento en 100 kg, y la relación grava/arena se incrementó de 0,4 a 1,0 con pulg. grava. La pérdida de la microfibra se redujo considerablemente ya que, en el diseño original, gran parte de esta fibra se perdió en el rebote. Este proceso también redujo el riesgo de obstruir las bombas que sacaban agua de la mina, al reducir la cantidad de material rebotado en el drenaje.

Fig. 6: La fibra suelta en la mina drena debido al rebote del proceso de hormigón proyectado (entre 10 a 12% de pérdida por rebote.

Fig. 7: El aspecto del hormigón está diseñado con el Polímero Superabsorbente (SAP) con fibra incluida. Genera solo una pérdida del 1,6% por rebote.

Fig. 8: Prueba de desplome y apariencia del hormigón original con fibra incluida. Con valores de 10 a 12% de pérdida por rebote y con pérdida de fibra.

Fig. 9: Prueba de hundimiento y apariencia del hormigón utilizando el polímero superabsorbente (SAP) con fibra incluida. Con un valor de 1,6% de pérdida por rebote.

Otras ventajas observadas en el shotcrete donde se utiliza la savia incluyen:

- Superficies de elementos verticales o de relleno de formas irregulares, (elementos donde el curado apropiado es muy difícil de aplicar). La integración de la savia en la mezcla imprime una liberación controlada de humedad, dándole el curado interno necesario para la hidratación del cemento Portland, reduciendo el riesgo de grietas formadas en el estado plástico, y reduciendo la contracción seca causada por el número de partículas finas que contiene.
- El proceso de shotcrete se realiza en condiciones favorables con menos polvo ya que parte del agua está en forma de gel.
- El manejo y dosificación de la savia es simple ya que son cantidades más pequeñas de sólo unos pocos gramos por metro cúbico de hormigón
- Es una tecnología compatible con la mayoría de los aditivos utilizados en la industria de las mezclas y tiene una excelente correlación con superplastificantes de tipo policarboxilato.
- Incluye un alto grado de cohesión y adhesión a la mezcla
- Reduce el porcentaje de pérdida en aplicaciones aéreas
- La reducción del rebote implica una mejora en el rendimiento volumétrico y un ahorro de tiempo en la ejecución, ya que no es necesario cubrir áreas con múltiples pasadas, ya que las capas más gruesas son posibles con menos deformaciones.

Fig. 10: Hormigón proyectado diseñado con Polímero Superabsorbente (SAP) con excelente trabajabilidad, bombeabilidad y adhesión con el sustrato en un ambiente muy limpio sin polvo ni brisa prácticamente sin rebote.

CONCLUSIONES

El uso de la savia ha demostrado generar beneficios esenciales para el diseño de shotcrete, principalmente en sus propiedades reológicas, donde tradicionalmente, las correcciones se hacían a través de las multas de cemento y/o materiales cementosos suplementarios, estos últimos no siempre disponibles o costosos de conseguir. Entre las propiedades que mejora los diseños de mezcla se incluyen mayores proporciones de grava/arena, evita un alto consumo de finos para obtener propiedades reológicas, mejora la trabajabilidad, bombeabilidad, adherencia al sustrato, reduce la pérdida de rebote, mejora la cohesión, evita la pérdida de materiales ligeros utilizados en las mezclas, por ejemplo las fibras sintéticas y/o el uso de agregados ligeros, no aumentan el aire en el hormigón y es compatible con la mayoría de los aditivos utilizados en la industria de las mezclas. Al liberar humedad de manera controlada, genera un curado interno que reduce el riesgo de agrietamiento y favorece la hidratación del cemento Portland en elementos donde es difícil aplicar procesos de curado convencionales.

__JOSÉ JUAN FLORES MARTÍNEZ__, ingeniero geológico graduado de la Facultad de Ingeniería de la Universidad Nacional Autónoma de México. Actualmente es director de la compañía Innovación y Solución en Polímeros y trabajó en el Centro de Tecnología Cemento y Concreto del Grupo CEMEX. Con más de 25 años de experiencia en el análisis petrográfico, con aplicación en la resolución de problemas de calidad de agregados para hormigón y hormigón endurecido, además de ser profesor en la Facultad de Ingeniería, UNAM impartiendo las asignaturas de Petrología, Petrología sedimentaria y Petrología metamórfica, también ha escrito y publicado varios artículos en revistas y conferencias nacionales e internacionales.

The Use of Rapid-Set Accelerators in Shotcrete

By Raúl Bracamontes

Shotcrete has become a prevalent lining technique in tunnel, mining and underground construction for many years. The ability of shotcrete to form on most shapes and its ability to bond to uneven surfaces make it a highly versatile material that provides effective and economical ground support with the benefit of quick and easy application. Key performance indicators of shotcrete are setting time and strength, which are decided by not only mixture design but also by the use of accelerator. The accelerator alters the hydration mechanisms of the cementitious material, influencing its strength development and setting time. Shotcrete rapid-set accelerator is a liquid admixture designed to be injected into the wet mix shotcrete at the nozzle, inside the air flow in some wet mix applications. It must comply with ASTM 1141 type II grade 9 Quick-Setting Accelerating Admixtures for shotcrete. Though not covered directly in this article, dry powdered rapid-set accelerators can also be provided in prebagged dry-mix shotcrete materials.

Alkali-free liquid accelerators, offering advantages of high efficiency, high strength, and environmentally safe, have gained in popularity. Today, 5 - 8% of accelerators recommended for shotcrete. Also, in practice the alkali-free accelerators are most common, rather than the outdated alkaline accelerators.

STRENGTH CLASSES (EN 14487-1)

Shotcrete of ages under 24 hrs. is generally considered "fresh shotcrete" or "green shotcrete." Early-age shotcrete is then described as shotcrete that is 1–3 days old after application. As a result, the strength of freshly applied shotcrete is divided into three classes: J1, J2, and J3.

Class J1 sprayed concrete is appropriate for application in thin layers on a relatively dry substrate. No structural requirements are to be expected in this type of sprayed concrete during the first hours after application.

Class J2 sprayed concrete is used in applications where thicker layers have to be achieved within a short period of time. This type of sprayed concrete can be applied overhead and is suitable even in difficult circumstances; for example, in cases of slight water intrusion or immediate subsequent nearby work such as drilling and blasting.

Class J3 sprayed concrete is used in cases of highly fragile rock or strong water intrusion. Due to its rapid setting, more dust and rebound occurs during the application and therefore, class J3 sprayed concrete is only used in special cases.

The minimum compressive strength of shotcrete to allow personnel reentry back to a sprayed zone is typically specified as 145 psi (1 MPa) in underground construction.

Some strength requirements for underground support during the early age of a shotcreted area are outlined in Table 1. Sometimes mistakes are made, primarily in accelerator dosage, with overdosing at the nozzle creating big problems.

An overdose of accelerator can cause problems like lower compressive strength than that of the control mix, increased porosity, decreased durability, increased permeability, and reduced resistance to freezing and thawing (Fig. 2). The damage will be most severe if you have a high water/cement ratio.

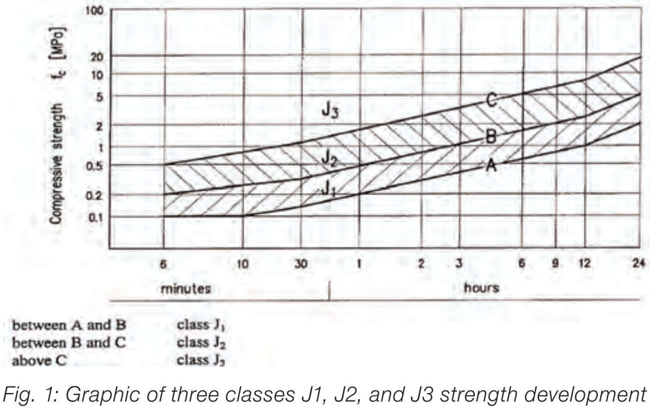


Fig. 1: Graphic of three classes J1, J2, and J3 strength development

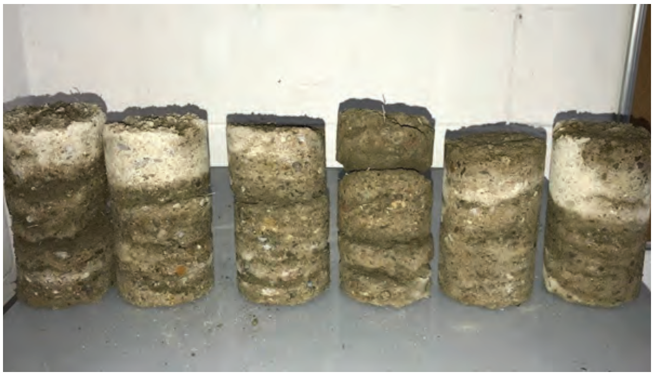


Fig. 2: Cores of shotcrete with an overdose of accelerator

Time	Early strength (kg/cm²)			*Early strength (psi)*		
	J1	**J2**	**J3**	***J1***	***J2***	***J3***
6 min	0	2	5	*0*	*28*	*71*
10 min	1	2.5	6.6	*14*	*35*	*94*
30 min	1.5	4	12	*21*	*56*	*171*
1h	2	6.1	18.2	*28*	*86*	*259*
3h	4.1	12	35	*58*	*171*	*498*
6h	6.4	18.3	52.9	*91*	*260*	*752*
9h	8.3	23.5	67.4	*118*	*334*	*959*
12h	10	28	80	*142*	*398*	*1140*
24h	20	50	160	*284*	*711*	*2280*

Table 1: Early-age compressive strength gain

The European's EFNARC specification limits the loss of final compressive strength to 20% when using an accelerating admixture. That requires a shotcrete mixture designed for 20% over the specified mixture to get the strength required. EFNARC also recommends the use of alkali-free accelerators for permanent linings.

In a case study, a test was carried out on shotcrete with 28.1 lb/cu ft (450 kg/m³) of cement with a uniform w/cm and using sodium silicate as an accelerator (alkaline accelerator), the dosage of the latter was varied solely and exclusively, dosed based on the weight of the cement.

The effect of a sodium carbonate accelerator on the hardened properties of dry-mix shotcrete was reported in *Durability of Dry-Mix Shotcrete Containing Rapid-Set Accelerators*. As part of the study, a shotcrete mix containing 4% sodium carbonate accelerator by weight of cement was compared to a control shotcrete mix containing no accelerator. Both mixtures had a cement-sand ratio of 1:4. The 28-day compressive strength of the accelerated shotcrete was 54% lower than that of the control mix. Perhaps more importantly, the accelerated shotcrete had reduced freeze-thaw resistance (ASTM C 666). Concrete specimens are generally considered to have acceptable freeze-thaw resistance if they lose less than 5% of their weight after 300 freeze-thaw cycles. After 311 freeze-thaw cycles, the control mix suffered a weight loss of only 0.9%. The accelerated shotcrete, however, lost 7.3% of its weight after 153 cycles and 17.1% after 210 cycles, at which time all three specimens failed. Since then, rapid-set accelerator technology has improved providing much better performance.

The principle behind the calibration of peristaltic pumps used for injecting accelerator is to determine the amount of

Dosage sodium silicate	compressive strength (kg/cm²)	*compressive strength (psi)*
0%	480	*6830*
5%	385	*5480*
10%	295	*4200*
15%	225	*3200*
20%	175	*2490*
25%	122	*1740*
30%	84	*1200*
35%	51	*725*
40%	37	*526*
45%	26	*370*
50%	22	*313*

Table 2: Concrete compressive strengths with different alkaline accelerator dosages

piston volume (l)	strokes per minute	concrete volume per minute (l)	concrete volume per hour (m^3)	cement quantity (kg/m^3)	cement quantity per hour	accelerator dosage	amount per hour of accelerator (kg)	accelerator density (kg/l)	liters per hour	liters per minute
14.6	15	219	13.14	465	6110.1	7%	427.71	1.44	297.02	4.95
14.6	16	233.6	14.016	465	6517.44	7%	456.22	1.44	316.82	5.28
14.6	17	248.2	14.892	465	6924.78	7%	484.73	1.44	336.62	5.61
14.6	18	262.8	15.768	465	7332.12	7%	513.25	1.44	356.42	5.94
14.6	19	277.4	16.644	465	7739.46	7%	541.76	1.44	376.22	6.27
14.6	20	292	17.52	465	8146.8	7%	570.28	1.44	396.03	6.60
14.6	21	306.6	18.396	465	8554.14	7%	598.79	1.44	415.83	6.93

Table 3: Example of accelerator pump calibration (metric)

Pump piston volume (ft)	strokes per minute	concrete volume per minute (ft^3)	concrete volume per hour (yd^3)	cement quantity (lb/yd^3)	cement quantity per hour (lb)	accelerator dosage	amount per hour of accelerator (lb)	accelerator density (lb/gal)	gal per hour	gal per minute
0.52	15	7.8	17.33	783.8	13585.87	7%	951.01	12.0	79.25	1.39
0.52	16	8.32	18.49	783.8	14491.59	7%	1014.41	12.0	84.5	1.4
0.52	17	8.84	19.64	783.8	15397.32	7%	1077.81	12.0	89.81	1.5
0.52	18	9.36	20.80	783.8	16303.04	7%	1141.21	12.0	95.1	1.58
0.52	19	9.88	21.96	783.8	17208.76	7%	1204.61	12.0	100.3	1.68
0.52	20	10.4	23.11	783.8	18114.49	7%	1268.01	12.0	105.6	1.76
0.52	21	10.92	24.27	783.8	19020.21	7%	1331.41	12.0	110.9	1.84

Table 4: Example of accelerator pump calibration (US Units)

accelerator admixture that must be pumped in one minute to meet the design requirements of the shotcrete. The amount of additive to be pumped is directly tied to the amount of cementitious material in the mixture design. For this reason, the volume released at each piston of the stationary concrete pump and the pumping speed expressed in strokes per minute must be known.

It's the nozzleman's responsibility to calibrate the pump and the admixture pump to guarantee quality shotcrete is placed.

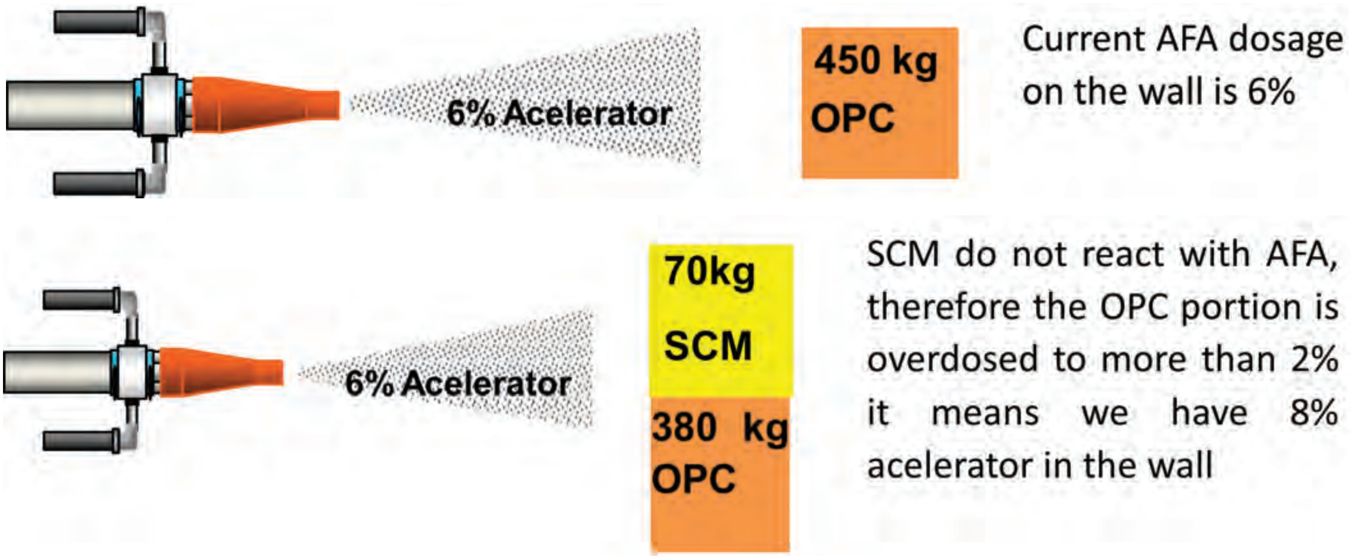


Fig. 3: Blended cements can cause an overdose of the accelerator on the OPC portion

Fig 4: Overhead panel with an overdose of accelerator during placement. When the concrete hits the panel it set immediately and did not flow around the reinforcing bars leaving voids behind

EXAMPLE WITH THE FIRST ROW OF TABLE 3 IN METRIC UNITS

Let's say we have one shotcrete equipment with the volume released at the piston is 14.6 l.

Multiplying the volume of the piston by the number of strokes determines the quantity of accelerator released into the concrete pumped in one minute would be 14.6 x 15 = 219 l.

By multiplying the result obtained by 60 min and dividing by 1000 l we determine the amount of accelerated concrete in m^3 pumped in one hour. 219 x 60 min / 1000 l = 13.14 m^3

Multiplying 13.24 by the amount of cement per m^3 of concrete determines the amount of cement used. 13.24 x 456 = 6110.1 kg.

By multiplying 6110.1 kg by the required dose of additive we determine the amount of additive in kg required. Then, dividing by the density (1.44 kg/l) we can determine the amount of additive required in liters 6110.1 x 7.0% = 427.71 kg 427.71 / 1.44 = 297.02 / 60 min = 4.95 l per minute.

The pumping frequency measured in hertz is regulated in the peristaltic accelerator pump to pump 4.95 l of additive. This is measured in a test tube to guarantee the correct dosage of additive in the concrete mixture.

EXAMPLE WITH THE FIRST ROW OF TABLE 4 IN US UNITS

Let's say we have one shotcrete equipment with the volume released at the piston is 0.52 ft^3.

Multiplying the volume released at the piston by the number of strokes determines the quantity of accelerator released into the concrete pumped in one minute, 0.52 x 15 = 7.8 ft^3.

By multiplying the result obtained by 60 min and dividing by 27, we determine the amount of concrete in yd^3 pumped in one hour, 7.8 x 60 min / 27 = 17.33 yd^3.

Multiplying 17.33 yd^3 by the amount of cement per yd^3 of concrete determines the amount of cement used. 17.33 x 783.8 = 13585.87 lb.

Finally, by multiplying 13585.87 lb by the required dose of additive we determine the amount of additive in lb required. Then, dividing by the density (12.0 lb/gal) we can determine the amount of additive required is 13585.87 x 7.0% = 951.01 lb 951.01 / 12.0 = 79.25 gal / 60 min = 1.32 gal per minute.

The pumping frequency measured in Hertz is regulated in the peristaltic pump with which it is possible to pump 11.01 fl oz of additive. This is measured in a test tube to guarantee the correct dosage of additive in the concrete mixture.

Some equipment has an interactive PLC system which means an integrate flow rate adjustment will automatically adjust the amount of accelerator with the pumping velocity.

Blended cements need a higher dosage of accelerator since the OPC portion needs to react faster to obtain the desired setting (Fig. 3).

Remember when you are shooting around reinforcing bar, the level of acceleration has to be reduced to allow the concrete to flow around the bars with the shotcrete placement (Fig. 4). It is usually recommended to use at 3% of the weight of cement.

BIBLIOGRAPHY

1) Dipl.-Ing. Jürgen Höfler, Putzmeister AG, Dipl.-Ing. HTL Jürg Schlumpf, Sika Services AG, Dipl.-Ing. FH Markus Jahn, Sika Services AG "Sika Sprayed Concrete Handbook" 4 Edition 08/2011

2) Raul Bracamontes "Manual para el diseño y aplicación del concreto lanzado" 2da edición

3) Abbas Mohajerani, Daniel Rodrigues, Christian Ricciuti, Christopher Wilson, "Early-Age Strength Measurement of Shotcrete", Journal of Materials, vol. 2015, Article ID 470160, 10 pages, 2015. https://doi.org/10.1155/2015/470160

4) "Durability of Dry-Mix Shotcrete Containing Rapid-Set Accelerators," ACI Materials Journal, May-June 1992, pp. 259-262.

5) ASTM C 1141 Standard Specification for Admixtures for Shotcrete 2015 EDITION

Raúl Armando Bracamontes Jiménez, Ing.*, graduated from ITESO University (Instituto de Estudios Superiores de Occidente) in 1994 with a degree in civil engineering and has been working in the concrete industry ever since. Currently the owner of ADRA Ingeniería S.A. de C.V. since 2005, he is fluent in Spanish and English with multiple publications and courses given on shotcrete on his résumé. He is an ACI Certified Wet-Mix Nozzleman and Approved Examiner. Bracamontes is a member of Instituto Mexicano del Cemento y del Concreto (IMCYC), Colegio de Ingenieros Civiles de León (CICL), and the American Shotcrete Association.*

Clear Vision: Integral Dust Reduction in Dry Mix Shotcrete Mixes

Given its impact on construction site safety, dust exposure is a key consideration on almost any jobsite. Continued increases in OSHA regulations around allowable exposure to airborne particulates has impacted the tools and procedures required for dust-heavy construction work activities. Because concrete repair projects commonly involve dusty activities in confined spaces, additional planning and precaution must be taken to counteract dust generated from any applicable repair activities. Given all these considerations, manufacturers and installers of pre-packaged dry-mix shotcrete have been challenged with developing materials and methods for mitigating dust on a traditionally high-dust activity.

Flexibility, efficiency, and cost effectiveness drive dry mix shotcrete as a popular application method for concrete repair. With the increasing amount of planning and equipment associated with high dust environments, some contractors go as far as actively avoiding dry-mix shotcrete due to the regulations surrounding dust mitigation. The changes involved with reducing dust on a concrete repair site often result in significantly more time in engineering and construction planning, increasing the overall cost of a project. This shift to different materials and methods in aspirations of a safer work environment resulted in a clear call to action for dry-mix shotcrete manufacturers: develop a single component dry-mix shotcrete with reduced dust generation, without impacting key qualities of the material.

WHAT CAUSES DUST IN SHOTCRETE?

Because of the nature of cementitious materials, dust prevention can be extremely difficult. The small particles associated with cement, sand, and other powders are key contributors to dusty environments, especially in installation areas common for shotcrete. At a fundamental level, dust is generated when these small particles are agitated in the absence of hydration. In the case of dry mix shotcrete, there are two clear avenues for dust to occur: at the dry-mix hopper and at the nozzle. As shown in Fig. 1, between material being dumped into the hopper, and the agitation of the dry material once inside, the dry-mix hopper area traditionally emits quite a bit of dust, especially when placed in a confined space.

Fig. 1: Dry Material Hopper

The second, and more commonly identifiable generator of dust in the shotcrete process is the shooting process itself, as shown in Fig. 2. The dust created at the nozzle, also known as rebound, generally occurs in high concentrations relative to safety standards and therefore requires additional oversight and protective equipment. Once the equipment is started up and calibrated, the nozzleman uses the shooting process to adhere material to the repair area, but in the process, material is lost as rebound, often creating a dusty environment for the duration of the activity.

When significant dust and high rebound occur, a lower amount of material is applied to the repair area, resulting in an inefficient use of material, in addition to creating dust exposure. As ACI 506 details, aggregate selection in a shotcrete mix design plays a significant role in rebound (ACI Committee 506, 2016). If sands not meeting ACI 506 gradations are used, material performance could be compromised. Aggregate gradation is key when discussing

Fig. 2: Dry Shotcrete Application

shotcrete performance, as approved gradations have been designed to ensure proper compaction and account for the rebound of larger particles. Given the disproportionately high rebound of larger particles, a shotcrete containing a properly graded aggregate will create less rebound and therefore dust, than a shotcrete with a sand containing more coarse particles. Dust does occur naturally on job sites due to the nature of handling and spraying dry material, but the shotcrete material itself can also influence dust generation, and so, re-engineering the shotcrete material can contribute to a more efficient product.

Observing Dust on Site - OSHA regulations around Permissible Exposure Limits (PELs) are a factor in the planning around respiratory dust exposures at construction sites. In the case of Total Respirable Dust, just one factor in construction safety planning for airborne respirable particulates, the OSHA PEL is currently **5 mg/m³** (OSHA, 2021). Typically dust concentrations are quantified by measuring airborne particulates over different areas around the job site and developing a concentration based on the volume of air. Research has shown that for dry mix shotcrete work, dust concentrations can average **25.6 mg/m³** (KESSEL, REDL, MAUERMAYER, & PRAML, 1989). A similar experiment using wet mix shotcrete reported the average dust concentration at the highest exposure area to be **15.8 mg/m³** (Li, Zhou, Chen, Liu, & and Xiao, 2019). Based on the nature of the different mix methods, the significant reduction in dust concentration from dry- to wet-mix corroborates field insights that have led some installers to shift away from dry-mix shotcrete.

ADVANCES IN DUST REDUCTION TECHNOLOGY

However, the additional equipment and time often associated with wet-mix shotcrete has led to the demand for a lower dust dry-mix material. As previous American Shotcrete Association articles have shown, significant research has been conducted by manufacturers in attempts to reduce dust in dry-mix shotcrete. Historical tests indicated that success in dust reduction has been consistently met with some combination of durability challenges, lower later-age strengths, or reduced early strengths (Clements & Fournier, 2020). Over the last few years, there have been breakthroughs in the technology associated with dry-mix shotcrete additives that have allowed for low dust alternatives to come to market.

For example, US Concrete Products has developed a proprietary admixture, now used in a dry-mix shotcrete product, that has allowed for a 95% reduction in dust compared to traditional dry-mix shotcrete, based on NIOSH 0600 and 7500. When combined with properly graded aggregate per ACI 506, the admixture functions as a dust and rebound suppressant. In similar experiments to those mentioned above regarding measured dust concentration, between two different on-site experiments, the resulting maximum dust exposure averaged 2.45 mg/m³, with neither measurement exceeding 3.0 mg/m³. These experiments, which measured the dust exposure of every crew member over a several hour period, not only indicated a significant dust concentration reduction compared to both historical dry-mix and wet-mix shotcrete experiments, but also showed an exposure level below the OSHA PEL. See full results of the two experiments in Fig. 3.

Position	Test 1 Dust Exposure (mg/m³)	Test 2 Dust Exposure (mg/m³)
Mixer	**2.90**	0.95
Nozzleman	0.98	**2.00**
Finisher 1	0.31	0.18
Finisher 2	0.26	0.20
Helper	0.25	N/A

Fig. 3: USCP Field Dust Exposure Monitoring Results

Unlike previous dust reduction technology, this new admixture has minimal impact on the physical properties of the dry-mix material, meaning material strength and durability are consistent with traditional shotcrete products. The admixture has been included in the single component mix, which can be installed like any other dry-mix shotcrete, but the resulting process includes significantly less rebound and therefore dust. As expected, less material lost to rebound indicates that more material ends up installed, reducing waste. By reducing dust without impacting other material properties, the resulting product is not only safer, but a more efficient material for completing a dry-mix shotcrete repair.

CONCLUSION

Understanding what causes dust on any concrete repair site allows for the proper mitigation measures to be put in place to minimize field exposure. In the case of dry-mix shotcrete, understanding the relationship between manufacturer mix design and rebound can make a large difference in terms of dust exposure, allowing for the optimal material selection. Although there are many available dust mitigation techniques used to reduce environmental dust on a jobsite, they often take time to set up, incur additional costs, and most importantly, may not fully protect the workers completing the concrete repairs from dust exposure. Integral dust reduction technology in bagged shotcrete material is a large step for dry-mix shotcrete, as it represents a safer, more efficient material that can be used leveraging well-proven installation techniques.

REFERENCES

ACI Committee 506. (1990). Guide to Shotcrete. *American Concrete Institute.*

Clements, W., & Fournier, C. (2020). Developing Dust Reduced and Low Cracking Potential Dry-Mix Shotcrete Mixes. *American Shotcrete Association.*

KESSEL, R., REDL, M., MAUERMAYER, R., & PRAML, G. J. (1989). Changes in lung function after working with the shotcrete lining method under compressed air conditions. *British Journal of Industrial Medicine.*

Li, P., Zhou, Z., Chen, L., Liu, G., & and Xiao, W. (2019). Research on Dust Suppression Technology of Shotcrete Based on New Spray Equipment and Process Optimization. *Advances in Civil Engineering.*

OSHA. (2021). *US Department of Labor Occupational Safety and Health Administration.* Retrieved from PARTICULATES NOT OTHERWISE REGULATED, TOTAL AND RESPIRABLE DUST: https://www.osha.gov/chemicaldata/801

Tommy Brennan, USCP Sales Engineer, *holds a Bachelor of Science in Mechanical Engineering from the University of Massachusetts, Amherst, and has spent his entire career in construction related roles. After over four of years leading the construction of major capital projects, as a Project Engineer with ExxonMobil in Houston, he joined USCP in October of 2021 to further his career with cementitious materials. Tommy currently oversees the QC program, assists with Sales and Operations, and leads development of new products for USCP. A detailed understanding of USCP's product offer has also made Tommy instrumental in sourcing raw materials and admixtures needed to maintain competitive pricing and lead times for manufacturing projects. From an industry perspective, he is an ACI Field Technician I certified and an active member of the American Shotcrete Association as well as the ICRI Baltimore-Washington chapter.*


LARGE JOB OR SMALL, WHATEVER THE APPLICATION AND MIX, WE HAVE THE RIGHT STYLE AND SIZE STATIONARY PUMP FOR MAXIMUM EFFICIENCY AND PROFITABILITY
INFO@OLINPUMP.COM
714 897 1230 X2
OLINPUMP®
CONCRETE - SHOTCRETE - GROUT
ADSC The International Association of Foundation Drilling
asa
PDCA WWW.PILEDRIVERS.ORG
DEEP FOUNDATIONS INSTITUTE DFI®
Concrete Pump CPMA Manufacturers Association
PROUDLY BENEFITTING GARY SINISE FOUNDATION

CORPORATE MEMBER PROFILE

With the aim of providing the construction industry with a better option for concrete waterproofing, Ron Yuers founded Kryton International Inc. in Vancouver, Canada, in 1973. Before then, professional builders mainly had external waterproofing membranes to rely on for protection. While these products could provide some help, they were prone to failure. Realizing that, Ron worked alongside a chemist for hundreds of hours in a laboratory in search of a more reliable solution and came up with Krystol® technology.

When added to a concrete mix, this technology would enable concrete to chemically react to incoming water. That reaction would then create interlocking crystals, which fill up the pores and micro-cracks of the concrete, blocking pathways for water to pass through. In effect, it turns the concrete into its own waterproof barrier without the need for external membranes.

It created a whole new category of concrete waterproofing that was first applied to the Boeing Developmental Center in the USA to great success and has spread in popularity around the world, allowing Kryton to grow and offer services in more than 50 countries.

KRYTON TODAY

Nowadays, Kryton's focus is not just on improving the waterproofing process for the construction industry. We have branched out to offer solutions for improving concrete durability and overall quality. Because of that, building professionals have access to an award-winning concrete hardening admixture and equally award-winning concrete sensors, which come with a robust monitoring platform that collects temperature and strength data all in one place.

With these and our waterproofing system, building professionals have more options at their convenience for extending the life span of their concrete structures. Whether that's through making the concrete impermeable, giving it better resistance against abrasion and erosion, getting a better idea of how the concrete is developing, or doing all three, we're here to help.

But we don't just support building professionals with our solutions. We also strive to advocate for better, more sustainable construction practices through multiple industry-leading organizations, such as the American Shotcrete Association, American Concrete Institute, and the International Concrete Repair Institute.

SHOTCRETE APPLICATIONS

Due to our wide array of concrete activities, we have something to offer everyone in the industry, including shotcrete specialists.

Our waterproofing admixture, Krystol Internal Membrane™ (KIM®) can be used with shotcrete mixtures to give waterproof concrete at the time of shotcrete installation without the hassle of applying and protecting an external membrane.

Fig. 1: Kevin Yuers, Kryton VP, and Mary Grace Rosalin, Research Center Supervisor, testing if they can force water through the concrete samples - permeability testing

This can be done for the following shotcrete applications:

- Below-grade parking
- Basements
- Wastewater treatment plants
- Swimming pools
- Dams
- Foundation walls
- Water storage tanks
- Canals

Those who want more durable shotcrete can add our hardening admixture, Hard-Cem®, instead. That will increase the shotcrete's resistance to abrasion and erosion, which will in turn create a structure that has up to double the wear life even under harsh conditions. With its additional resiliency, the structure will require less maintenance, and that can cut down on the additional concrete needed for repairs or replacements, reducing the structure's lifetime carbon footprint.

Some of the shotcrete applications that benefit the most from this solution include:

- Skateboard parks
- Tunnels
- Shafts
- Dams
- Sluiceways
- Spillways
- Drainage conduits
- Stilling basins
- Culverts
- Canals

FEATURED PROJECT

One of the more well-known shotcrete projects Kryton assisted with is the TELUS Garden. Located in Vancouver, Canada, this project was a $750-million investment for TELUS Communications. It was designed to be the company's new national headquarters, and it would include a 24-floor signature office tower alongside a 53-floor residential tower that would house 425 homes. Below all that, there would be a six-level parkade.

The project decision-makers wanted this parkade to be fully waterproof to protect the structure from water ingress. But they were concerned about the possibility of any external waterproofing failing and that it might contain petroleum, which would hinder their goal of LEED certification.

To avoid the use of external membranes they went with 1,600 m^3 (2,100 yd^3) of the KIM admixture. That allowed the project team to waterproof all six parkade levels without the need for installing and potentially repairing an external membrane, which significantly sped up the process of construction. This ensured the team could build walls faster and move on to other critical aspects of the project, including waterproofing the surrounding construction joints, penetrations, and control joints with the Krystol® Waterstop System.

It all led to a fully waterproof foundation for TELUS Communications' new headquarters and both a LEED Platinum and LEED Gold certification.

Fig. 2 & 3: Telus Garden

KRYTON INTERNATIONAL INC

1645 East Kent Avenue
Vancouver, BC Canada
604.324.8280
Kryton.com

Restoring a Treasure on the Hudson

Originally published by WaterShapes Online (www.watershapes.com)

By Bill Drakeley

Fig. 1: Built during an era when Mid-Century architecture was sweeping the nation, the Neumann house stands as an example of enduring modern design.

Marcel Breuer's Neumann House was built in 1953 for textile designer Vera Neumann, a prominent socialite and friend of the rich and famous. The house is by all measure a masterpiece of the mid-century modern architecture. Our company, Drakeley Pool Co., completed an historic renovation of the swimming pool as part of an overall restoration of the historic residence.

Drakeley Pool Co. takes on a broad range of projects, from massive commercial installations to super high-end residential projects. The company also refurbishes historic watershapes, a discipline that requires careful adherence to the original design. Featured here, Bill Drakeley shares a simple gem of a project designed by 20th Century modernist master, Marcel Breuer.

It's located in an upscale neighborhood in Croton-on-Hudson, N.Y. on a ridge overlooking the famed river of the same name. The pool is an artistic statement. As far as we know, it was never used much for swimming, but as more of architectural element that ties the landscape to the home's architecture.

The pool was badly in need of repair and upgrading, but at the same time, we had to comply with historic restoration protocols; meaning we had to fix it without disrupting the original design, construction and materials, as much as possible.

Participating in historic restorations of this kind is always interesting and often a point of pride. Preserving the region's proud design history aligns well with a company like ours that has been part of the community for seven decades.

RECAPTURING THE PAST

This was not the first time our company has worked on a home designed by Breuer. Back in the early 2000s, we were engaged to take on a remodel of the pool at the Stillman House in Litchfield, Conn., which remains one of our favorite projects.

That project holds great meaning for our family. My maternal grandfather, Joseph N. Scott, Sr., founder of Scott Swimming Pool Co., one of the pioneering pool builders in Connecticut and the broader New England region, built the pool in the 50s, at a time when Breuer was doing pioneering residential design in the region.

Our family is very proud of Joe Scott's legacy. He was a WWII vet, fought at the Battle of the Bulge and after the war, got into septic system work. It wasn't long before he moved from handling waste water to building swimming pools, which were experiencing rapid growth in the post-war era. He was quite a guy and many, many years ago, I found my own start in the pool industry working for his company.

My grandfather knew how to network and was friends with Breuer, and with legendary abstract sculptor, Alexander Calder. The Stillmans were avid art collectors and commissioned Calder to create a stunning outdoor mural, which was prominently situated at one end of the pool. It was a prestigious project back then, with a renowned architect and world-famous artist. The mural itself is a stirring representation of the surrounding natural landscape.

Fast forward about 50 years and the pool and mural had fallen into decay. In part because our company had a shared history, but also because we were qualified to take on the project, we were hired to renovate the pool, and as part of the work, restore the mural.

The pool was not unlike many other remodels we've done, albeit with the requirements of an historic restoration, but the mural, that was a group effort. We consulted with the Calder Foundation and a host of experts and concerned parties. (See our original *WaterShapes* article on the project, Artful Restoration.)

In the end the pool looked brand new, as did the mural.

NEW SKIN

During the Stillman project, we came to know the owners, who are active purchasing historic homes, restoring them and selling them. It's a kind of house-flipping on an extremely rarified level.

They had purchased the Neumann house and were in the process of restoring it to its original form with appropriate upgrades throughout the property. We had developed a good relationship and based on our past work together, we were successful in securing the contract.

The pool is nestled in beautiful local granite stone retaining walls and is a terrific example of integrating a watershape into architectural hardscape, which is present on the house and throughout the project. When we became involved, the pool was hardly recognizable. It was filled with dirt and debris, and hadn't been used in years. Aesthetically and functionally, it was completely derelict.

Fig. 2: The pool was in a state of severe decay. Our goal was to restore it as closely as possible to its original form.

Fig. 3 & 4: Some of the details, such as the spillway, were antiquated, but staying true to the design, we were able to restore the pool's hydraulic function.

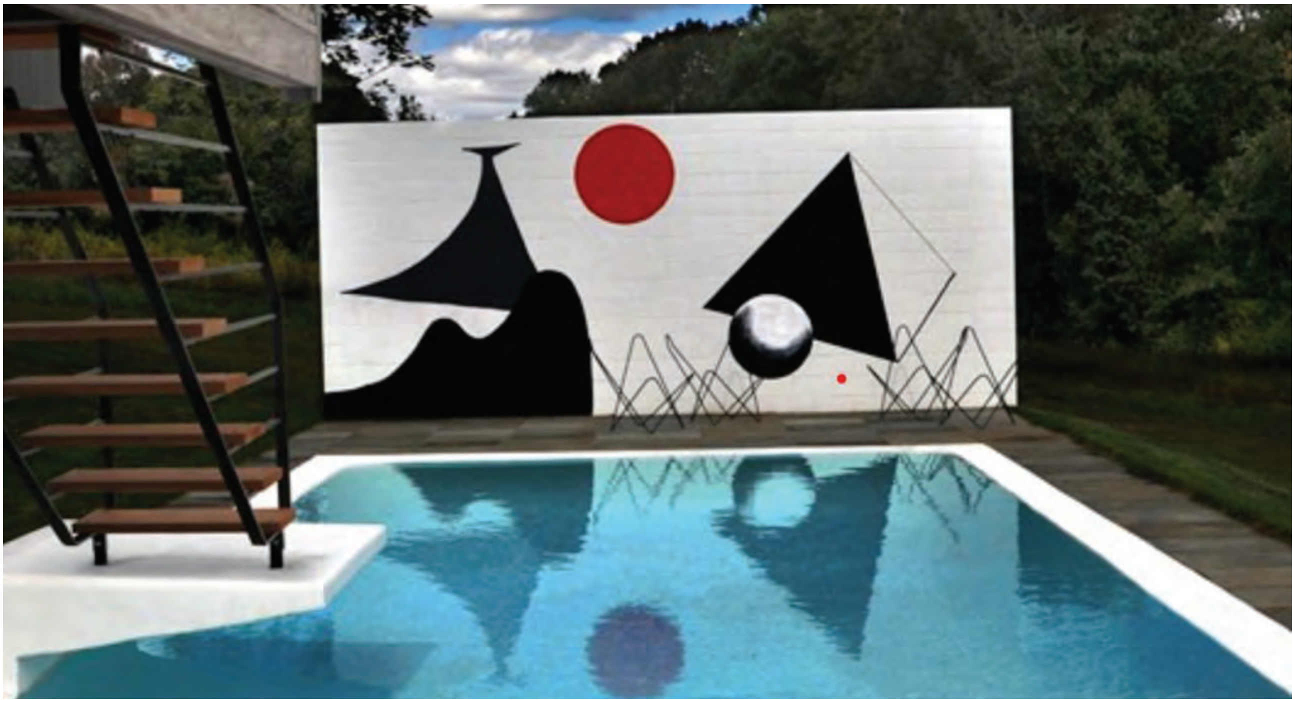


Fig. 5: The Stillman house is another example of a Marcel Breuer project our company restored. The mural was originally created by legendary artist Alexander Calder, but because of the ravages of time, had to be completely restored with the help of local art historians.

We immediately saw the opportunity to reclaim the pool from the ravages of time and neglect. The structure was in disrepair with cracks and deteriorated concrete, it didn't hold water, but we knew it was fixable and didn't need to be completely removed. We were confident we could restore it to its original form, with upgraded equipment.

Like the house itself, the pool design was minimalist, featuring clean lines, bright white and sky-blue water. The whole pool is shallow, four feet (1m) deep, made of cast-in-place concrete, with a spectacular view of the Hudson River.

We sand-blasted the pool and performed numerous shell repairs, removing and replacing badly decayed material in a number of spots. Obviously, we had to make sure it was water- proof, so we installed a heavy-grade steel mesh, 6 in. (150 mm) on center and then shot a 4 – 6 in. (100 mm - 150 mm) structural interior skin.

It was a wet-mix shotcrete application using smaller-than-usual aggregate stone material, not getting above a quarter-inch aggregate. The largest aggregate used in shotcrete is 3/8 in. (10 mm), but we wanted to keep it nice and trim, and paintable, (more on the paint job below).

The wet-mix material was troweled smooth into place. We did have some shrinkage cracks, which were repaired, and the old bond beam was renovated with a white cementitious material and vibrated into place.

The new skin did shrink the interior of the pools, but working with the clients and the powers that be, we determined that was the least intrusive way to bring it back to something very close to its original form.

The pool includes an overflow through a scupper-like opening, then pours through a grate to a sub-grade catch basin on the downhill side. It's an early version of a water-in-transit design. We refurbished the catch basin and installed new plumbing from the basin to the equipment pad. We also replumbed the suction lines from the pool itself.

A PAINTED FINISH

It was common back in the 50s to finish pools with paint. In this case, the original was done in a white cementitious pool paint, instead of plaster, which hadn't yet caught on in those days. Specifically, this was a dry-gun, troweled, painted white surface.

It's interesting, when you compare the look of the paint to white plaster. It's a much softer look that beautifully stands out, especially in sunshine. It's not a look we see very often these days, but it makes a beautiful statement, perfect for a pool of this historic pedigree.

William "Bill" Drakeley *is an award-winning shotcrete technologist specializing in concrete science and construction, particularly shotcrete applications, techniques, and standards, with thirty-plus years of experience in shotcrete installation, water feature and geotech design and construction. He is co-founder of Watershape University.*

ACI COMMITTEE CHAIR APPOINTMENTS

ACI C660 –Shotcrete Nozzleman Certification Committee appoints a new Chair! The Committee welcomes Frank Townsend (Patriot Shotcrete) as Chair. He joins William Drakeley (Drakeley Pools Company), Secretary, as they lead this Certification Committee tasked "to develop, maintain, and update programs for use in certification of persons performing as shotcrete nozzlers." The Committee met for the first time, with Townsend as chair, this past October at the ACI 2022 Fall Concrete Convention in Dallas, TX. Randle Emmrich (Coastal Gunite Construction Company) stepped down after 6 years as Chair. We thank Emmrich for her faithful, thorough, and efficient direction during her tenure.


Frank Townsend


William Drakeley


Marc Jolin

ACI C661 – Shotcrete Inspector Certification Committee also appoints a new Chair! The Committee welcomes Marc Jolin (Laval University) as Chair. The Committee again thanks former Chair, Randle Emmrich (Coastal Gunite Construction Company) for her leadership as the first Chair of the committee and serving for 7 years, through the development and initial implementation of this program, prior to Jolin's appointment. At their recent meeting, also at ACI's 2022 Fall Concrete Convention, the Committee confirmed the acceptance of the Associate Shotcrete Inspector Certification. This allows candidates who pass both the Shotcrete Inspector exam and the ACI Concrete Field Tech Certification – Grade I, within the same year, to receive the Associate designation. The Associate then has 5 years to fulfill the required 3 years of work experience for upgrading to the full Shotcrete Inspector certification.

LAURO LACERDA - NEW CHAIR FOR UCA'S WG12


Lauro Lacerda

Lauro Lacerda, PE is the new chair for UCA's WG12 for 2022-2023. The UCA's Working Group 12 is tied to the International Tunneling Association WG12 based in Europe. The US group meets virtually every 2 or 3 months and have about 10 members representing tunneling and mining contractors, consultants and suppliers. The group's main objective for the year is to gather input from members and other organizations to advance: (1) collaboration between EFNARC and ACI in regards to mechanize shotcrete spraying certification; (2) RETC2023 shotcrete short course; and (3) ASA's position paper #5 on early strength shotcrete testing methods. They also try to have guess speakers at their meetings and plan to host Max Eckstein, President of EFNARC, at the next meeting.

Mr. Lacerda holds a B.Sc. and M.Sc. degree in mining engineering with specialization in rock mechanics. He has over 35 years of experience in tunneling and mining project engineering including concrete/shotcrete infrastructure design and application. Lauro was awarded ASA's 2007 Carl Akeley award with Knut Garshol for the paper, "Watertight Permanent Shotcrete Linings in Tunneling and Underground Construction." He is currently Senior Account Manager with Normet in Salt Lake City, Utah. If you want to join UCA's WG12 send him a note at Lauro.lacerda@normet.com.

AMERICAN CONCRETE PUMPING ASSOCIATION ANNOUNCES – NEW SAFETY DIRECTOR


Tabah Nez

The ACPA is pleased to announce the association's first dedicated safety director: Tabah Nez. This inaugural position was created to further ACPA's safety and certification programs for concrete pumping professionals.

As ACPA Safety Director, Nez will be responsible for developing and overseeing all safety and risk management activities, including safety programs, committees, bulletins and resources. His role will be instrumental in developing the training curriculum for ACPA University, an online training platform to be launched January 2023.

"I look forward to using my knowledge and experience to help shape a world-class safety resource for the concrete pumping industry," says Nez.

Nez brings to this position 23 years of professional hands-on experience in the areas of occupational, safety and health management; environmental health and safety management; risk prevention programs; management of construction emergencies; safety training and worker's comp claims management. He has served on the American Society of Concrete Contractors Executive Safety Committee. He holds a Bachelor of Science degree in occupational safety and health from Columbia Southern University and is OSHA-certified from the University of California, San Diego.

"Hiring a dedicated safety director is a milestone in ACPA's history. I'm excited for this next chapter and the impact it will have on our members," says Christi Collins, ACPA Executive Director.

For more information about the ACPA, visit www.concretepumpers.com.

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: *What is the efficiency of dry-mix shotcrete? How much is over spray vs. how much sticks to the surface?*

Answer: Dry-mix shotcrete may have more rebound (coarse aggregate that bounces off the surface) than wet-mix so it may be considered a little less efficient. However, predampening and the use of special nozzles can increase wetting and reduce rebound which makes the dry-mix efficiency approach wet-mix. Rebound may be estimated as 5 to 15%, with an average of 10% of the weight of the concrete materials. The experience and placing technique of the nozzleman can substantially affect the amount of rebound in either dry-mix or wet-mix. Overspray is much less and may depend on wind conditions and placing techniques. When looking at the overall efficiency of shotcrete placement in a given section, dry-mix materials can be tailored much closer to the actual need while wet-mix may have minimum concrete delivery volume and time constraints that would end up not using all the material delivered. Also, dry-mix has approximately ¼ the production rate of wet-mix, so in high-volume placements, wet-mix may have a natural advantage in productivity.

Question: *Is it true that shotcrete compression tests are more accurate and are likely to be higher (better) results? Basically, is there a difference when testing wet-mix shotcrete applied pneumatically as compared to simply being taken directly in cylinders from the batch plant or ready-mix delivery?*

Answer: Shotcrete placement provides full consolidation of the concrete by high-velocity impact. Concrete placed into cylinders for testing is consolidated by multiple rodding in three layers. Shotcreting also has some percentage of rebound so the concrete mixture that remains in the panel is more paste-rich than the mixture entering the pump. Thus, shotcrete placement may provide better consolidation, and a more paste-rich in-place mixture resulting in higher compressive strengths. However, shotcrete compressive strength is evaluated by cores extracted from panels. The coring process can create microcracking in the exterior surface of the core and produce slightly lower compressive strength than cylinders that have no damage to the outer surface when removed from the cylinder form and tested. Overall, there doesn't seem to be a significant difference when evaluating the concrete material's strength by shotcrete placement or concrete cylinders taken before pumping.

You could establish a correlation on a specific project by taking cylinders before pumping and then shooting material test panels. Then testing the cylinders and cores from the panel at the same age.

Question: *I was wondering if ASA has any safety meeting/tailgate presentations on high-pressure shotcrete work. I need to ensure my team knows how to properly disconnect hoses and align proper fitting procedures. Furthermore, do you have any guidance on a repair procedure for the rubber hose?*

Answer: We have an ASA document, "Safety Guidelines for Shotcrete," that addresses shotcrete safety. It is not a job-specific safety plan but gives you guidance on the information you may include in your plans. You can find it on our bookstore at https://shotcrete.org/bookstore/?product-page=2. A free copy of the Safety Guidelines is provided to all of our corporate and sustaining members. Membership also provides many other benefits, including discounts on shotcrete nozzleman certification and participation in our committees. We have a committee specifically devoted to Education and Safety for shotcrete that is very active.

Regarding the repair of the rubber hose, there is no procedure to repair any breaches in the hose itself. A damaged or excessively worn hose should never be used as the pressure that builds when a delivery line plugs during pumping is extremely dangerous. Modern pumps can reach 2000 psi (14 MPa) internal concrete pressure when experiencing a plug and the hose must be capable of carrying that high pressure. The wet-mix shotcrete hose is heavily reinforced, and the couplings are designed for high pressure. Your crew must be sure that all clamps are fully engaged on the heavy-duty couplings, and that safety pins are in place.

Question: *We have an existing historic 4 in. (100 mm) hollow clay tile wall that is finished with a 3-coat gypsum plaster. We would like to spray shotcrete on the non-finished side of the wall to strengthen it. Will the application of shotcrete on the back side of the wall possibly damage the historic plaster and paint? Will there be too much of a vapor drive from the application for the plaster to hold? Have you experienced plaster deterioration or loose keys from the application of shotcrete on the backside of a wall?*

Answer: As long as the hollow clay tile wall is rigid and stable, the shotcrete application should not impact the finished side plaster. Shotcrete impacts in a very localized area directly where the material stream is hitting the substrate. Research shows that the localized force is about 90 to 100 lbs (40 to 45 kg) when shooting directly on the substrate. If shooting a thicker wall using a benching method, most of the force is carried by the previously shot material, so it would have less impact. If the clay tile needs to be stiffened, an initial thin layer could be shot to provide additional thickness before the final thickness is placed. Though we don't have any specific information about vapor transmittal, concrete used in shotcrete placement inherently has a low w/cm and less water in the mixture to bleed or create vapor. We haven't had any reports of plaster or grout falling off the inside of masonry walls that have been structurally enhanced with shotcrete.

Question: *We have a client that has requested a shotcrete application for a dirt crawlspace. The facility is located in the Northeast part of New York. I'm not the designer, but I believe we are looking at a wet-mix, applied at a 4 in. (100 mm) depth throughout the crawlspace. I had a few questions I was hoping could get answered as we move through the technical specifications process.*

1. *Is there an off-season for the shotcrete product? Does it have to be applied in warm weather? Again, this is upstate NY.*
2. *What kind of equipment is used to dispense/place the product? (same as concrete?)*
3. *What is the noise level of the dispensing equipment? Typical of any concrete pour or much louder? The facility is a childcare center, so they are concerned about noise levels.*

Answer: Here are the answers in the same order as your list.

1. Shotcrete is just a placement method for concrete, so there is no "off-season." However, as with cast concrete, cold weather placement needs more planning and material delivery controls. As wet-mix shotcrete material is predominately delivered by ready-mix trucks, the concrete should be delivered at 50°F (10°C) or higher. Then once shot, if temperatures are less than 50°F, the concrete should be protected by insulated blankets or the area enclosed by vented heaters to keep temperatures above 50°F. We also don't want to shoot onto frozen surfaces.
2. We use small line concrete pumps standard in the concrete industry.
3. Concrete pumps and air compressors are generally diesel-powered engines. Pump engines range in horsepower from 75 to over 200 hp, depending on the pump size. Your application is of relatively low volume, so one of the smaller pumps should do fine. We also use relatively small air compressors, and many contractors who work in residential or metropolitan areas use equipment equipped with sound reduction. The sound at the point of placement where the air-accelerated material stream exits the nozzle is generally just the sound of the airflow.

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.

FOR MORE INFORMATION ON ASA AND ITS PROGRAMS, CONTACT:

Phone: (248) 983-1712 | Fax: (248) 965-9188
E-mail: info@shotcrete.org

american shotcrete association | asa

SHOTCRETE CALENDAR

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

FEBRUARY 26, 2023	**Shotcrete Contactor Education** Ojai Valley Inn | Ojai, CA
FEBRUARY 26 – 28, 2023	**ASA 2023 Shotcrete Convention & Technology Conference** Ojai Valley Inn | Ojai, CA
FEBRUARY 26 – 28, 2023	**ASA 2023 Spring Committee Meetings** Ojai Valley Inn | Ojai, CA

Sunday, February 26, 2023

Time	Meeting
4:00 – 5:00 PM	Pool & Recreational Shotcrete Committee

Sunday, February 26, 2023

Time	Meeting
12:30 – 1:30 PM	Membership Committee
1:30 – 2:30 PM	Marketing
3:00 – 4:00 PM	Underground
4:00 – 5:00 PM	Contractor Qualification Committee

Sunday, February 26, 2023

Time	Meeting
8:00 – 9:00 AM	Education & Safety Committee
9:00 – 10:00 AM	Board of Directors – Part I
10:30 – 11:30 AM	Board of Directors – Part II

FEBRUARY 26 – MARCH 1, 2023	**SME Annual Conference & Expo 2023** The Colorado Convention Center | Denver, CO
MARCH 14 – 18, 2023	**CONEXPO-CON/AGG 2023** Las Vegas Convention Center | Las Vegas. NV
APRIL 2 – 6, 2023	**ACI 2023 Spring Concrete Convention** Hilton San Francisco Union Square | San Francisco, CA
APRIL 17 – 19, 2023	**ICRI 2023 Spring Convention** JW Marriott Parq Vancouver | Vancouver, BC Canada
MORE INFORMATION	To see a full list, current updates, and active links to each event, visit www.shotcrete.org/calendar.

NEW ASA MEMBERS

american shotcrete association | asa

SUSTAINING CORPORATE

Geo-Rope Ltd. (Canada)
Toronto, ON, Canada
www.geo-rope.com
Primary Contact: Niall McLean
nm@geo-rope.com

Lanford Brothers Company, Inc.
Roanoke, VA
www.lanfordbrothers.com
Primary Contact: Ken Lanford
kenl@lanfordbros.com

CORPORATE

Western Specialty Contractors
St. Louis, MO
westernspecialtycontractors.com
Primary Contact: George Justice
georgej@westerngroup.com

Joseph J Albanese, Inc
Santa Clara, CA
www.jjalbanese.com
Primary Contact: Dan Dryden
ddryden@jjalbanese.com

Geobuild, LLC
Bethel Park, PA
www.geobuild.com
Primary Contact: Lisa Mercurio
lmercurio@geobuild.com

Ralph L Wadsworth Construction Company
Draper, UT
www.wadsco.com
Primary Contact: Brian Tolley
btolley@wadsco.com

Coastal Drilling East LLC
Mt Morris, PA
www.coastaldrillingeast.com
Primary Contact: David Harris
dharris@shaftdrillers.com

Terra Engineering & Construction Corporation
Madison, WI
www.whyterra.com
Primary Contact: Stacy McCoy
smccoy@whyterra.com

Green Infrastructure Partners Inc
Toronto, ON, Canada
gipi.com
Primary Contact: Rodrigo Fragachan
rfragachan@gipi.com

Zolula (Pty) Ltd
Stellenbosch, Western Cape, South Africa
www.zolula.co.za
Primary Contact: Adriaan Havenga
adriaan@zolula.co.za

SUSTAINING CORPORATE ASSOCIATES

Brett Dietrich
Lanford Brothers Company, Inc
Roanoke, VA

Orey HIll
Lanford Brothers Company, Inc
Roanoke, VA

SUSTAINING CORPORATE COMPANY

Geo-Rope Ltd
Caldercruix, Airdrie, United Kingdom

STUDENT

Jongbeom Kim
Universite Laval
Québec, Canada

INTERESTED IN BECOMING A MEMBER OF ASA?

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

ASA Sustaining Corporate Members

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

Geo Craft Builders
www.geocraftbuilders.com

CanCrete Equipment Ltd.
www.cancrete.ca

Curtis Concrete Pumping
www.curtisconcretepumping.com

Dees-Hennessey, Inc.
www.deeshenn.com

Maple Site Solutions
www.maplesitesolutions.ca/

Consolidated Shotcrete Inc.
www.consolidatedshotcrete.ca

REED Shotcrete Equipment
www.reedpumps.com

Coastal Gunite Construction Company
www.coastalgunite.com

EdenCrete
www.edencrete.com

Geo-Rope Ltd. (Canada)
www.geo-rope.com

Construction Forms
www.ConForms.com

MAPEI Underground Technology Team
www.utt-mapei.com

Cost of Wisconsin, Inc.
www.costofwisconsin.com

The Quikrete Companies
www.quikrete.com

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

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

Gulf Shotcrete, LLC
www.gulfshotcrete.com

Baystate Shotcrete, LLC
www.baystateshotcrete.com

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

Lanford Brothers Company, Inc.
www.lanfordbrothers.com

Master Builders
www.master-builders-solutions.com

INDEX OF ADVERTISERS