2015

THE EFFECT OF SPRAYING ON FIBER CONTENT AND SHOTCRETE PROPERTIES

Marc Jolin
Laval University

J.-D. Lemay
Research Center on Concrete Infrastructures

N. Ginouse
King Shotcrete Solutions

B. Bissonnette
Laval University

É. Blouin-Dallaire
Laval University

THE EFFECT OF SPRAYING ON FIBER CONTENT AND SHOTCRETE PROPERTIES

M. Jolin[1], J.-D. Lemay[2], N. Ginouse[3], B.Bissonnette[1] and É. Blouin-Dallaire[4]

[1] Full professor, Research Center on Concrete Infrastructures, Department of Civil and Water Engineering, Laval University, Quebec City, Qc, Canada; PH: 1-418-656-3163; Email: marc.jolin@gci.ulaval.ca
[2] Research Engineer, Research Center on Concrete Infrastructures, Quebec City, Canada
[3] R&D Leader, King Shotcrete Solutions, Boisbriand, QC, Canada
[4] M.Sc. Candidate, Laval University, Quebec City, Canada

ABSTRACT

The addition of fibers in shotcrete is a well-established practice in many underground applications. Indeed, fiber reinforced shotcrete, or FRS, typically exhibits improved resistance to crack opening as well as substantial energy absorption. The latter is often found to be a key element in controlling the extent of damages and providing minimum safety to worker in the event of microseismic activity. This energy absorption capacity, or *toughness*, is developed when the fibers increase the work necessary to propagate a crack; therefore, this mechanism is highly dependent on the type of fiber used, the quality of the matrix, and, obviously, the actual amount of fibers present in the *in-place* mixture.

The study reported in this paper was devoted to the effect the pneumatic placement and consolidation mechanisms have on the *in-place* fiber content and the resulting shotcrete properties, namely compressive strength and toughness. Indeed, it has been reported in the past that the amount of *fiber* rebound can be much higher in proportion than the other constituents in the overall rebound losses. The experimental results show a complex relationship between the hardened matrix properties and the fiber content, leading to an optimal toughness value that does not necessarily corresponds to the higher fiber content or higher compressive strength. It should be noted that all the results were obtained from shotcrete test panels prepared in a laboratory-controlled environment, using typical shotcreting equipment.

Finally, the mechanisms behind the pneumatic placement and incorporation of fibers in a layer of shotcrete are discussed, based on the most recent observations made in the laboratory using a high speed imaging system.

INTRODUCTION

Shotcrete is a placement method where concrete is pneumatically applied, its high placement velocity ensuring the in-place consolidation. The technique makes shotcrete quite well adapted for applications such as tunneling, repairs, slope stabilization, and others for which conventional placement methods would often be inefficient or economically unviable. When fibers are included in the shotcrete mixture design (fiber reinforced shotcrete or *FRS*) the material typically exhibits improved resistance to crack opening as well as substantial energy absorption. The latter is often found to be a key element in controlling the extent of damages and providing minimum safety to worker in the event of micro seismic activity or in rock-burst prone areas in underground construction.

Nevertheless, this advantageous and very popular placing method comes with an inherent loss of material on site due to rebound. Rebound is generally defined as material that ricochets off the receiving surface during shooting. Many factors related to the shooting parameters (process, air velocity, shooting angle, orientation, and placement thickness), mixture design (nature of the constituents and proportions) may affect the overall rebound. In both the dry-mix and wet-mix processes, experimental results show that the rebound losses can result in a significantly different *in-place* mixture composition, particularly with respect to the actual amount of *fibers* present in the in-place shotcrete layer (Banthia and al. 1994, Armelin and Banthia 1998a, Armelin and Banthia 1998b, Jolin 2001).

Keeping in mind the many varying parameters that can be involved in a spraying session, it was decided to investigate the effect of pneumatic placement on the resulting compressive strength and toughness (as measured with the *ASTM C1550, often referred to as the Round Determinate Panel* test) of a reference dry-mix shotcrete mixture. The goal was not to generate a wide range of data for support design, but instead gain a better understanding of the mechanisms and concepts involved and the resulting effects on the *in-place* composition of FRS.

SPRAYING CONCRETE: WHAT IS REALLY GOING ON DURING PLACEMENT?

Over the years, there has been a number of studies concentrating on shotcrete mixture design (Morgan and al. 1987, Ghio and Monteiro 1988, Armelin and Helene 1995, Jolin 1999, Pfeuffer and Kusterle 2001, Watanabe and al. 2010, Pickelmann and Plank 2012) in order to minimize rebound and improve mechanical properties. Some other studies have concentrated on pumping of the concrete, in the case of wet-mix process, to enable longer pumping distances or increase open time – or "pot-life" – and allow longer transport time (Kaplan and al. 2005, Jolin and al. 2009)

Only a few researchers have devoted time and efforts to really look into what is occurring during the pneumatic placement phase, i.e. from the moment the material exits the nozzle to the moment of impact on the receiving surface (Armelin and Banthia 1998a, Armelin and Banthia 1998b, Ginouse 2014a, Ginouse 2014c, Ginouse 2014b). The few available studies have led to very interesting findings, based upon which a conceptual framework has been developed, along with mathematical descriptions of the phenomena and mechanisms taking place during the placement phase. In the next section, some of these mechanisms and their possible effect on rebound, particularly rebound of fibers, are summarized.

A travelling aggregate…

To understand the effect of *pneumatic placement* on rebound and on the resulting *in-place* mix composition, one has to break down the placing process of shotcrete into an individual particle impacting an elastic-plastic-viscous substrate that is the fresh shotcrete. According to Armelin's work (Armelin and Banthia 1998a, Armelin and Banthia 1998b), the kinetic energy of the incoming particle, the mechanical properties of the substrate and its cohesion are all key parameters that determine whether the particle will get trapped in the in-place shotcrete or if it will rebound.

Rigorously speaking, however, it is the local mechanical, rheological and cohesive properties that are of interest (immediately around the incoming aggregate). Before an aggregate can be embedded into the substrate, there need to be appropriate local conditions or local properties. In Fig. 1(a), the local arrangement of paste and aggregates shown is such that the incoming aggregates will rebound. The upside to this loss of material is that the rebounding particles will leave some of their surrounding paste before being ejected and transfer compaction energy to the substrate. This phenomenon will happen until sufficient paste has accumulated on the surface to retain the aggregate (Fig. 1(b)). There is again an optimal combination of *substrate properties*, *impact energy* and *adhesion* between the paste and the aggregate to allow embedment of the incoming particle. To complicate things a little more, Fig. 1(c) depicts the situation where the *size* of the aggregates impacting the surface are different. In such case, the small aggregates *steal* the spot of some of the larger ones, and the latter hit the plastic shotcrete surface and the local conditions are such that they will rebound (in the case depicted, there is not sufficient paste to capture the particle). Not only does the difference in particle size result in higher rebound, but also, as shown in Fig.1(c), in a higher *in-place* paste content. This last case illustrates the importance the aggregate size distribution has on rebound and final in-place composition (Jolin and Beaupré 2004). In fact, it also illustrates the stochastic characteristics of the situations depicted in Figure 1; indeed, the *probability* of the next incoming particle to have a given size can be read directly off the aggregate size distribution curve since this curve is similar to a *cumulative probability density function*.

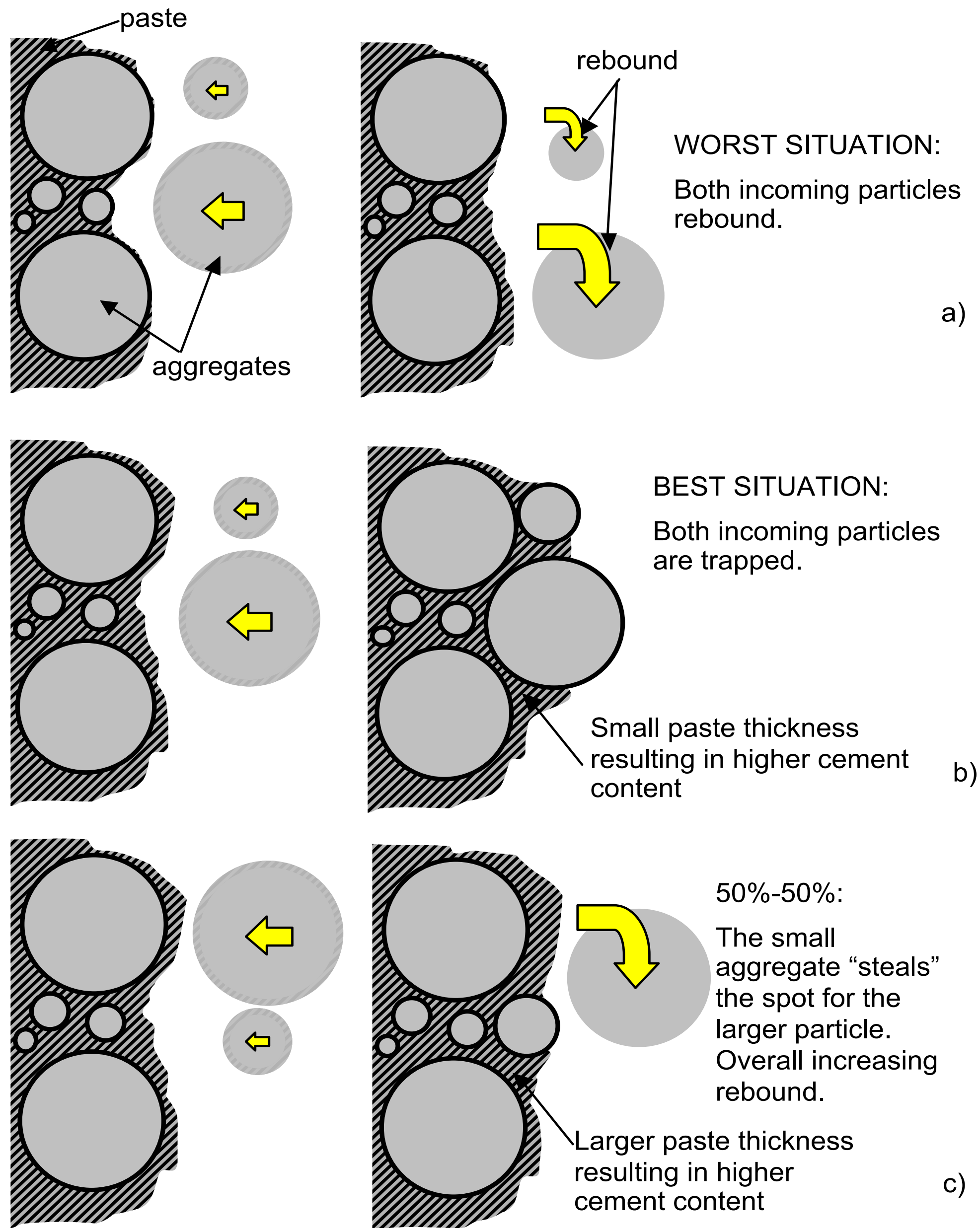

Figure 1: Travelling aggregates hitting a fresh shotcrete substrate (adapted from (Jolin 2004))

Now, if one looks at the situation from the perspective of the substrate properties, it is clear that they will play an important role on the outcome of the scenarios presented in Figure 1. Indeed, a stiff substrate will lead to higher overall rebound while a softer substrate will facilitate the retention or capture of the aggregate impacting it.

In fact, it is the rheology of the substrate that is of interest here. Assuming a Bingham-fluid behavior, one could describe the impact of an aggregate as a dynamic event that has to overcome the *yield stress* and then deform the substrate material where *viscosity* translates as the resistive force opposing the deformation. Although some interesting attempts have been made to correlate the rheological properties of dry-mix shotcrete and the resulting rebound (Armelin 1997, Pfeuffer and Kusterle

2001), it remains difficult to grasp the whole range of phenomena at play given the relatively stiff consistency of in-place shotcrete. In fact, some will say that in-place dry-mix shotcrete is to be considered as flowing only at *very high* shear strains (such as those found during the impact of an aggregate) and that conventional rheological tools can not be used. In addition, recent laboratory observations highlighted the likelihood that at the high shear rates encountered in dry-mix shotcrete placement, the Bingham fluid behavior is most probably not applicable (Armengaud and al. 2016). Indeed, in the presence of particular admixtures (e.g. air-entraining admixture) or pozzolans (e.g. silica fume or ground recycled glass (Fily-Paré 2015)), fresh dry-mix shotcrete behaves more like a *shear thinning* fluid, referred to as the *Herschel-Bulkley* model fluid. Figure 2 shows a graphical comparison between the typical rheological behaviors of Bingham and *Herschel-Bulkley* fluids. Given the fact that the nozzleman adjusts the shooting consistency based on a combination of both the "stiffness" of the freshly placed shotcrete (equivalent to the *yield stress*) and the imprint of the impacting aggregate (a high shear rate event), it is expected that different mixture designs may lead to very different placement behaviors and, therefore, a variable amount of rebound. Figure 2 summarizes the rationale behind this analysis, illustrating the mistake that can be made when trying to apply regular rheological measurements to dry-mix shotcrete due to the high shear rates encountered during an aggregate impact.

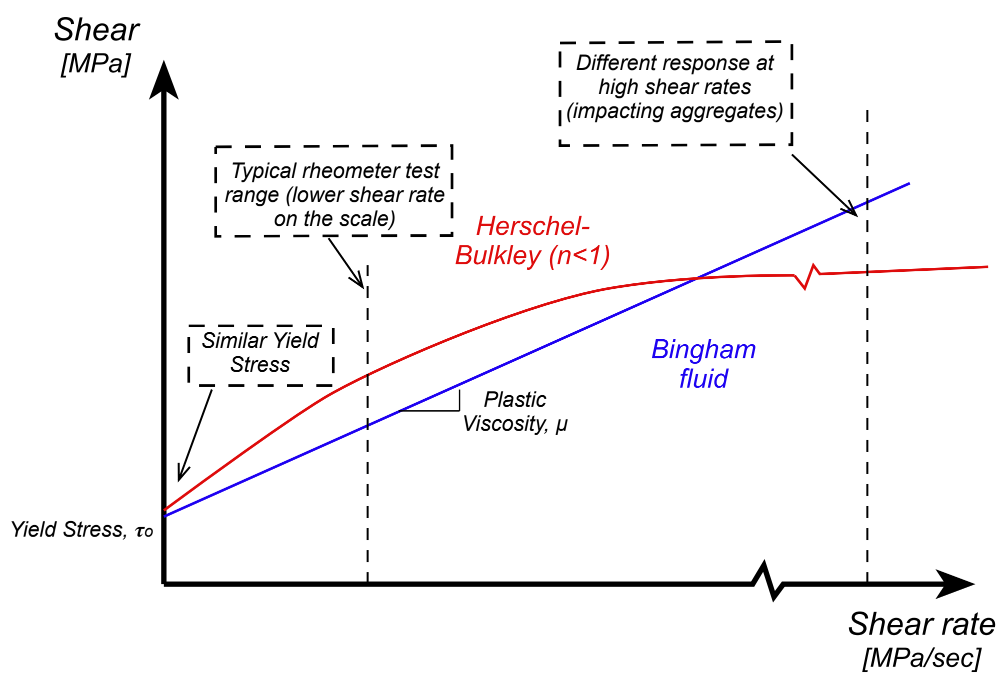

Fig. 2: Comparison between the typical rheological behaviors of Bingham and *Herschel-Bulkley* fluids .

Looking back at Figures 1 and 2, one can wonder how the different spaying parameters will affect placement and rebound. In its simplest definition, a "spray" is a *substance driven through air in the form of tiny drops* and can be described by the spatial distribution of the elements sprayed at different velocities, or more precisely, following a non-uniform velocity profile (Hattel and Pryds 2004). At the end of the spray (incoming stream), complex events take place during placement that result in *consolidation* of the material (e.g. creation of a continuous medium) and some losses due to rebounding particles. As said before, attention was paid in different studies to the phenomenon of rebound and ways to reduce it (Pfeuffer and Kusterle 2001, Jolin and Beaupré 2004, Bindiganavile and Banthia 2009, Kaufmann and al. 2013), but it is the work by Armelin (1997) that seems to have first shed light on the fundamental mechanisms (Armelin 1997, Armelin and Banthia 1998a, Armelin and Banthia 1998b, Armelin and al. 1999). Indeed, Armelin proposed a general equation based on energy, according to which the rebound of a single particle will occur if the rebound energy W_R (elastic energy released by the substrate) exceeds the debonding energy W_D. What makes it interestingly complex is that W_R and W_D are both function of the incident particle's kinetic energy and the substrate properties, in totally different expressions.

Based upon the previous discussion, it is easy to conceive that the presence of fibers in the mixture is likely to increase the complexity of the phenomena occurring during placement. For instance, if one considers the situation illustrated in Figure 1 with a fiber instead of an aggregate travelling toward the fresh substrate, the fiber orientation becomes a crucial aspect in the prediction of rebound. Applying recently developed measurements methods (Ginouse and Jolin 2014), knowledge of the fiber spatial and velocity distributions of fibers within the spray can be considered as a cornerstone in the quest of gaining a better understanding of the fiber reinforced shotcrete placement process.

EXPERIMENTAL PROGRAM

The experimental program reported herein was put together to yield a more fundamental understanding of the effect of fiber upon rebound and the resulting shotcrete properties.

Equipment and Mixture design

All tested shotcrete mixtures were produced in the *CRIB Shotcrete Laboratory* at Laval University, Quebec City, Canada. This unique facility allows to produce shotcrete indoors year-round, under well controlled conditions, using full-size industrial equipment (dry and wet processes).

The dry-mix shotcrete was sprayed using a rotating barrel ALIVA 246 pump equipped with a 38.1 mm interior diameter hose and a water ring located 3 m upstream from the outlet of the nozzle (Fig. 3). Shooting operations took place in a rebound chamber and were performed in accordance with standard practice (ACI 2005), at an average temperature of 21 °C. The standard *CRIB Shotcrete Laboratory* equipment includes an electronic air flow meter, a water flow meter and electronic scales. A data acquisition system records respectively the airflow, the water flow and the cumulative weight of material used during the spraying operations (Fig. 4). The targeted airflow is normally set at 5 m^3/min (180 CFM), whereas the water and dry material flows are used as quality control indicators. Irregular or non-uniform flows lead to the rejection of the test specimens produced and the necessity to start the operation all over. No such problems were encountered in this project.

Figure 3 – Dry-mix shotcrete equipment

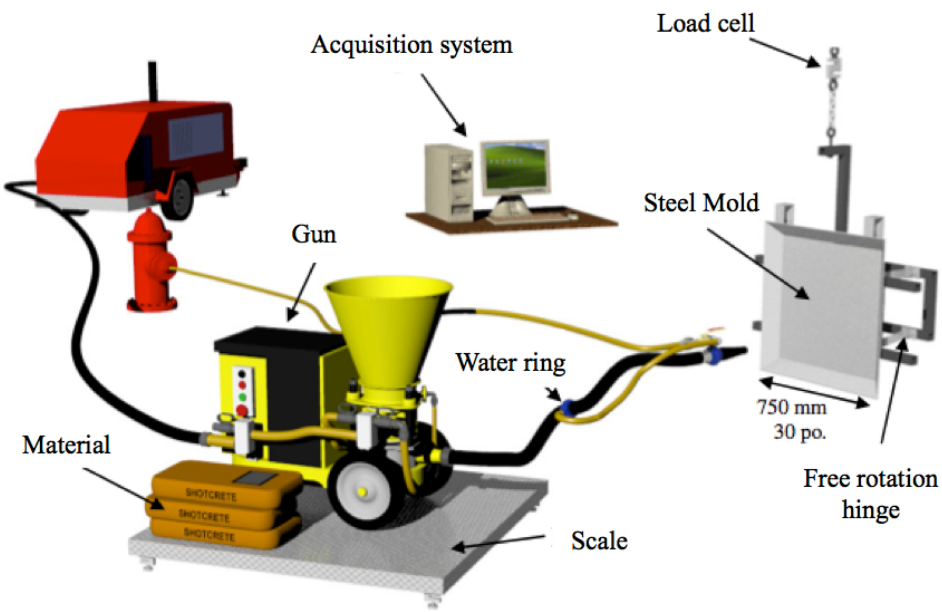

Figure 4 – Schematic illustration of the experimental used in the *CRIB Shotcrete Laboratory* for quality control and rebound measurements

Table 1 presents the proportions of dry constituents in the reference mixture, along with the corresponding *theoretical* composition of a cubic meter of the same mixture having a w/cm of 0.40 and an air content of 3.0 %. The fiber used is a typical hooked-end high tensile strength steel fiber, 30 mm in length and 0.55 mm in diameter. The dry constituents were pre-bagged in a dedicated plant.

Table 1: Investigated reference shotcrete mixture composition

Constituents	*Dry constituents [wgt. %]*	*Theoretical proportions* [kg/m³]*
Ordinary Portland Cement	19.4	416.5
Silica Fume	1.9	41.6
*Water **	-	*183.2*
Sand	63.3	1359.0
Coarse aggr. (ϕ_{max}: 10 mm)	15.3	328.8
Steel fibers	-	46.0
*Air content (%)**	-	*3.0*

* Assumed values, considering w/cm = 0.40 and air content = 3.0 %.

With the dry-mix shotcrete process, the nozzleman has control over the amount of water added at the nozzle and he makes use of this lever to adjust the material *consistency* to the specific jobsite conditions such as the type of application, orientation, thickness, reinforcement, etc. In this project, the water flow at the water ring was adjusted such as to shoot the investigated reference shotcrete mixture at three different consistency levels: *Normal, Wet,* and *Dry*.

The consistency deemed *Normal* is often referred to in the industry as the *wettest stable consistency*, where the material is shot so as to produce the lowest rebound possible without sagging or sloughing. The resulting surface of the freshly applied shotcrete is found to be uniformly damp in appearance (without excess water) and shiny. It corresponds to the optimal consistency level in most applications where reinforcing bars or other obstacles may be encountered and various finishing operation may be required. It is in fact common good practice in regular civil engineering applications, as well as in mining and tunneling applications.

The *Wet consistency* level corresponds to a situation where the nozzleman adds a little more water. Shotcrete is barely plastic enough to stay in place and exhibits a wet and somewhat soggy surface. The larger aggregates impacting can penetrate the surface to depth greater than twice their diameter.

At the other end of the moisture content spectrum, the *Dry* consistency level would correspond for example to a situation where the nozzleman reduces the amount of added water in order to improve adhesion to a wet surface. In this case, the surface of the freshly applied shotcrete is found to be dry in texture and larger incoming aggregates would only be partially embedded into the substrate. *Dry* consistency is known to lead to higher rebound and it is not suitable for shooting large surfaces. Nevertheless, considering the typically higher compressive strength resulting from the low water/cement ratio of the in-place material, it carries significant technical interest.

Testing program

The main goal of the testing program is to evaluate the energy absorption of dry-process shotcrete produced at different consistencies. To do so, standard test specimens were sprayed to conduct ASTM C1550 flexural strength tests, often referred to as the RDP – Round Determinate Panel tests. In order to provide further information and support the subsequent result analysis, the fresh shotcrete was sampled at the same time to measure the in-place fiber content. In addition, characterization tests on hardened shotcrete included ASTM C1604 compressive strength tests and ASTM C642 tests for the determination of absorption and volume of permeable voids, using 75 × 150 mm cores obtained from test panels in accordance with the ASTM C1604 procedure.

RESULTS

Compressive Strength

The results of the compressive strength tests performed at 7 and 28 days are presented in Table 2. Individual results are presented such as to appreciate the level of homogeneity achieved during shotcrete production in the laboratory.

Table 2: Compressive strength test results

Mixture consistency	*Individual 7-d results*	$f_{c\text{-}7\ d\ avg.}$	*Individual 28-d results*	$f_{c\text{-}28\ d\ avg.}$
		[MPa]		
Wet	37.3	37.2	47.0	47.8
	37.6		47.4	
	36.7		49.2	
Normal	44.4	44.7	56.7	55.7
	45.2		55.4	
	44.5		55.1	
Dry	56.5	54.8	63.3	63.6
	55.9		62.9	
	51.9		64.6	

It can be concluded from these results that the spraying *consistency* has a quite significant impact upon the mechanical properties of the in-place shotcrete. As found in previous studies (Armelin 1997, Jolin 1999), spraying at a drier consistency leads to a reduced water/cement ratio and therefore an increased compressive strength. It should be noted that in practice, it is usually recommended to shoot at the *wettest stable consistency* (Crom 1981, ACI 2009) in order to promote low rebound and yield adequate encapsulation of reinforcing bars.

Boiled water absorption and volume of permeable voids

The standard test method ASTM C642 – *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete* covers the determination of specific gravity, absorption, and volume of voids in hardened concrete. More specifically, the boiled water absorption and volume of permeable voids are used in the shotcrete industry as quality control indicators. Table 3 presents guidelines proposed in the literature, and that are generally accepted in the industry (Morgan and al. 1987) and Table 4 shows the actual results for this project.

Table 3: Suggested quality control indicators for shotcrete

Shotcrete Quality Rating	*Boiled absorption (%)*	*Volume of permeable voids (%)*
Excellent	< 6	< 14
Good	6 – 8	14 – 17
Fair	8 – 9	17 – 19
Marginal	> 9	> 19

Table 4: Determination of absorption and volume of permeable voids

Mixture consistency	*Boiled absorption (%)*	*Volume of permeable voids (%)*	*Rating (per Table 3)*
Wet	8.3	17.9	*Fair*
Normal	7.3	16.2	*Good*
Dry	5.7	13.1	*Excellent*

As expected, when the mixture consistency – and therefore the water/cementitious material ratio – decreases, both the absorption and the volume of permeable voids decrease. In the present case, the corresponding quality rating of the in-place material went from *fair* for the wet consistency to *excellent* for the dry consistency, the *Normal* consistency yielding the rating *Good*.

Evaluation of Flexural Properties

The flexural properties were evaluated following the ASTM C1550 – *Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete*. Tests were performed on three specimens for each shooting consistency level, at the age of 28 days. Table 5 summarizes the average test results. As often found elsewhere for this test, energy absorption data are reported here as a function of the vertical displacement recorded at the center of the round test panel, such as to offer a more complete picture of the FRS behavior.

Table 5: Flexural properties

Mixture consistency	*Average peak load (kN)*	*Average energy absorption* (Joules)*			
		5 mm	*10 mm*	*20 mm*	*40 mm*
Wet	30.5	99	182	302	441
Normal	35.5	115	209	333	470
Dry	39.1	97	168	267	392

* The numbers reported are the average of three test specimens and were all corrected for diameter and thickness, as specified in ASTM C1550-12a.

The peak load values recorded in flexure are consistent with the compressive strength results, as could be intuitively expected. Interestingly, the energy absorption results exhibit a slightly different trend, with the *Normal* consistency mixture dissipating more energy that the two other ones (respectively 7% and 20% more than the *Wet* and *Dry* consistency levels for a 40 mm displacement). In order to explain these results, the *in-place* fiber content was measured for all three mixtures. Considering the impact of water content on aggregate rebound and the in-place composition (Nagi and Whiting 1994), it could be expected that the fiber losses to rebound be influenced as well. Figure 5 presents a compilation of the mechanical test results obtained as a function of the consistency level, together with the corresponding in-place fiber contents (measured contents shown on top of the energy absorption bars). The absence of a trend between energy absorption and the fiber content likely reflects the complex relationship between rebound and the resulting material properties in shotcrete.

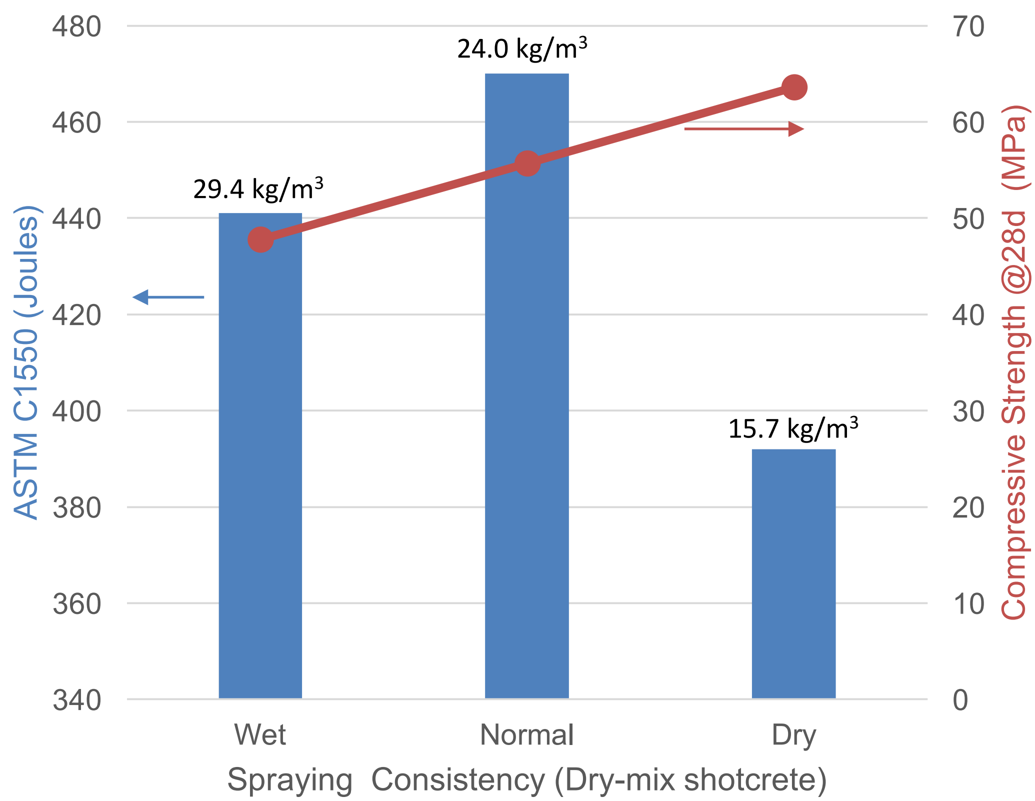

Figure 5: Cumulative energy absorption recorded after a 40 mm vertical central displacement (solid bars) and 28 d compressive strength (data points) expressed as a function of the shooting consistency level; the corresponding *in-place* fiber content is displayed above each bar.

DISCUSSION

The discussion is divided in two parts, addressing first dry-mix shotcrete and the overall effect of pneumatic placement, and then the efficiency of fibers in concrete in general.

Shotcrete is often defined as a method of placement where concrete is sprayed at sufficient velocity to achieve proper in-place compaction. The main drawback of the method is the inherent loss of material due to rebound. What past experiences have shown is that there is a complex relationship between mix design and shooting parameters that determine the given in-place concrete composition. The velocity of the particles exiting the nozzle, the substrate plastic properties and the aggregate gradation are all examples of parameters that play a role on the material ultimately found in-place. The result is a system where the in-place composition of the concrete can vary drastically from the initial mixture design. In general, with dry-mix shotcrete, the in-place mixture has a tendency to be richer in binder and poorer in coarse aggregate. This effect is directly related to the amount of rebound, which is in turn influenced by the amount of water added to the mixture.

Based on the results presented in Figure 5, fibers exhibit the same trend as the coarse aggregates with respect to rebound: the dryer the mixture, the higher the amount of fiber rebounds. In terms of energy absorption, the consequence is the combination of two opposite effects: the dryer shooting consistency favors higher strength, while it leads to reduced in-place fiber content. This turns out to be advantageous for practical purposes, the optimal results in terms of energy absorption corresponding to the *Normal* consistency level of shotcrete. Although this may seem counter intuitive, one must remember that the efficiency of a fiber in a concrete matrix is a complex relationship between bond and friction on the one hand, and the tensile strength and dosage of the fiber itself on the other hand (Bentur and Mindess 2007). The 30 mm long fibers were probably below the critical length since very little broken fibers (if any) could be observed on the fracture surfaces (Fig. 6). Hence, in analyzing the energy absorption values recorded experimentally, the parameters are reduced to friction, bond and the number of fibers present. Since it can be stated that bond, friction and compressive strength are somewhat proportional, the results of Figure 5 lead to the conclusion that there is an optimum combination of friction and fiber content, the optimum being, again, an intermediate bond strength and an intermediate fiber content.

Figure 6: Fracture surface of a RDP test panel; failure involves primarily pull-out of the fibers (*Normal* consistency level).

CONCLUSION

The research project reported in this paper was aimed at illustrating the complex relationship between rebound losses in dry-mix shotcrete placement and the resulting *in-place* material properties. Along with the initial discussion on the higher rebound proportions of large aggregates and fibers, the results presented allowed two interesting observations:

- As expected, shooting dry-mix shotcrete at a relatively *dry* consistency leads to higher in-place compressive strength values. It is however not desirable in practice, since it also results in higher rebound and reduced reinforcement encapsulation capability (Gagnon and al. 2004);
- In line with the trends highlighted for aggregate rebound, the wettest shooting consistency led to the highest in-place fiber content;
- The resulting *energy absorption* characteristics of in-place shotcrete is subject to the combined influence of two parameters upon which consistency have opposite effects: as consistency gets drier, the quality of the matrix and notably fiber bond increase, whereas the actual in-place fiber content decreases. As a result of these cross-effects, the highest recorded energy absorption corresponds to a shooting consistency close to the *Normal* level, which leads to an optimal combination of in-place mechanical strength and fiber content.

It is the hope of the authors that the results of this research project will help the industry better understanding the challenges involved in the design and testing of dry-mix shotcrete.

ACKNOWLEDGEMENTS

The authors are grateful to the Natural Sciences and Engineering Research Council of Canada (NSERC), King Shotcrete Solutions. and to the *Fonds de Recherche du Québec—Nature et Technologies (FQRNT)* for their financial support of this project.

REFERENCES

ACI (2005). 506R-05: Guide to Shotcrete. Farmington Hills, Michigan, USA, ACI International**:** 40.

ACI (2009). CP-60(09): Craftsman Workbook for ACI Certification of Shotcrete Nozzleman Farmington Hills, Michigan, USA.

Armelin, H. (1997). Rebound and Toughening Mechanisms in Steel Fibre Reinforced Dry-mix Shotcrete. Ph.D. Thesis, University of British Columbia.

Armelin, H. and Banthia, N. (1998a). "Mechanics of Aggregate Rebound in Shotcrete Part I." Materials and Structures, 206: 91-120.

Armelin, H. and Banthia, N. (1998b). "Mechanics of Aggregate Rebound in Shotcrete Part II." Materials and Structures, 207: 195-202.

Armelin, H., Banthia, N. and Mindess, S. (1999). "Kinematics of Dry-Mix Shotcrete." ACI Materials Journal 96(3): 283-290.

Armelin, H. S. and Helene, P. (1995). "Physical and Mechanical Properties of Steel-Fiber Reinforced Dry-Mix Shotcrete." ACI Materials Journal 92(3): 258-267.

Armengaud, J., G. Casaux-Ginestet, M. Cyr, B. Husson and Jolin, M. (2016). "Characterization of fresh dry-mix shotcrete and correlation to rebound." Construction and Building Materials in preparation.

Banthia, N., Trottier, J.-F., Beaupre, D. and Wood, D. (1994). "Properties of steel fiber reinforced shotcrete." Canadian Journal of Civil Engineering 21(4): 564-575.

Bentur, A. and Mindess, S. (2007). Fibre Reinforced Cementitious Composites. New-York.

Bindiganavile, V. and Banthia, N. (2009). "Effect of Particle Density on Its Rebound in Dry-Mix Shotcrete." Journal of Materials in Civil Engineering 21(2): 58-64.

Crom, T. R. (1981). "Dry-Mix Shotcrete Nozzling." ACI Concrete International, 1: 80-93.
Fily-Paré, I. (2015). Revalorisation du verre en béton projeté
Étude sur le remplacement partiel du ciment par de la poudre de verre en béton projeté par voie sèche. M. Sc., Université Laval.
Gagnon, F., Jolin, M. and Beaupré, D. (2004). Determination of criteria for the acceptance of shotcrete for Certification. Second Int. Conf. on Engineering Developments in Shotcrete , 4 oct 2004, Cairns, Queensland, Australia.
Ghio, V. A. and Monteiro, P. J. M. (1988). "The Effects of Polysaccharide Gum Additives on the Shotcrete Process." ACI Matérials Journal 95(2): 152-157.
Ginouse, N. and Jolin, M. (2014). Characterization of placement phenemenon in wet sprayed concrete. Proceedings of the 7th International Symposium on Sprayed Concrete: Modern Use of Wet Mix Sprayed Concrete for Underground Support, Sandefjord, Norway, 2014.
Ginouse, N., Jolin, M. (2014a). "Experimental and Numerical Investigation of Particle Kinematics in Shotcrete." Journal of Materials in Civil Engineering(June 2014).
Ginouse, N., Jolin, M. (2014b). "Investigation of spray pattern in shotcrete applications." Construction and Building Materials submitted in 2014.
Ginouse, N., Jolin, M., Bissonnette, B. (2014c). "Effect of equipment on spray velocity distribution in shotcrete applications." Construction and Building Materials 70: 7.
Hattel, J. and Pryds, N. (2004). "A unified spray forming model for the prediction of billet shape geometry." Acta Materialia 52(18).
Jolin, M. (1999). Mechanism of Placement and Stability of Dry Process Shotcrete Ph.D. Thesis, University of British Columbia.
Jolin, M., Beaupré (2004). Understanding wet-mix shotcrete; mix design, specifications and placement. Surface Support in Mining. S. Potvin, & Hadjigeorgiou. Perth, Australia, Australian Centre for Geomechanics**:** 263-267.
Jolin, M. and Beaupré, D. (2004). "Effect of the particle size distribution in Dry-process shotcrete." ACI Material Journal 101(2): 131-135.
Jolin, M., Beaupré, D., Mindess, S. (2001). "Rheology of dry-mix shotcrete." Concrete Science and Engineering, December 2001: 195-201.
Jolin, M., Burns, D. and Bissonnette, B. (2009). Understanding the pumpability of concrete. Conference on shotcrete for underground support, Davos, Switzerland, March 2009.
Kaplan, D., Larrard, F. D. and Sedran, T. (2005). "Design of Concrete Pumping Circuit." ACI Matérials Journal 102(2): 110-117.
Kaufmann, J., Frech, K., Schuetz, P. and Münch, B. (2013). "Rebound and orientation of fibers in wet sprayed concrete applications." Construction and Building Materials 49(0): 15-22.
Morgan, D. R., Neill, J., McAskill, N. and Duke, N. (1987). Evaluation of silica fume shotcrete. International Workshop on Condensed Silica Fume in Concrete, Montreal, Canada.
Nagi, M. and Whiting, D. (1994). "Determination of Water Content of Fresh Concrete Using a Microwave Oven." Cement, concrete and aggregates 16: 125-131.
Pfeuffer, M. and Kusterle, W. (2001). "Rheology and rebound behaviour of dry-mix shotcrete." Cement and Concrete Research 31(11): 1619-1625.
Pickelmann, J. and Plank, J. (2012). "A mechanistic study explaining the synergistic viscosity increase obtained from polyethylene oxide (PEO) and β-naphthalene sulfonate (BNS) in shotcrete." Cement and Concrete Research 42(11): 1409-1416.
Watanabe, T., Hosomi, M., Yuno, K. and Hashimoto, C. (2010). "Quality evaluation of shotcrete by acoustic emission." Construction and Building Materials 24(12): 2358-2362.