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Transport Properties of Wet-Mix Shotcrete

Lihe (John) Zhang
LZhang Consulting & Testing Ltd,

Dudley R. Morgan
LZhang Consulting & Testing Ltd,

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By Lihe (John) Zhang, Ph.D., P.Eng., LZhang Consulting & Testing Ltd, Vancouver, BC, Canada V4M 1S3. PH: 1-7787067198. Email: zhanglihe@gmail.com

Dr. Zhang is an Engineer at LZhang Consulting and Testing Ltd. He received his PhD in civil engineering in 2006 from the University of British Columbia, Vancouver, BC, Canada, where he conducted research on fiber-reinforced concrete. He is a member of ACI and Chair of ACI Subcommittee 506-F, Shotcrete-Underground; a member of ACI committee 506, Shotcreting; and ACI committee 544, Fiber-Reinforced Concrete.

D.R. (Rusty) Morgan, Ph.D., P.Eng. FACI. Vancouver, BC, Canada. Email: rustymorgan44@hotmail.com

Dr. Morgan was a member of ACI 506 and ACI 544 for over 30 years. He is a past President of the American Shotcrete Association. Dr. Morgan has published over 150 papers on concrete and shotcrete. He is a consulting engineer with over 40 years of experience on projects around the world.

With more and more wet-mix shotcrete being used in civil engineering and mining applications, the topic of the durability of shotcrete is receiving more interest. To achieve durable shotcrete structures, an understanding of the transport properties of shotcrete is critical. This research program investigates the transport properties of wet-mix shotcrete compared to cast-in-place concrete. Representative mixtures with binders comprised of cement, cement + fly ash, and cement + silica fume were cast with concrete mixtures, cast with shotcrete mixtures, and shot with shotcrete mixtures. Transport properties of boiled absorption and volume of permeable voids and rapid chloride penetration resistance were tested as part of a larger shotcrete transport properties study. Results show that when properly designed and applied, shotcrete can achieve equal, or better transport properties compared to cast-in-place concrete.

1.0 INTRODUCTION

Shotcrete technology has advanced dramatically in recent years due to its many advantages, including:

a) Compared to cast-in-place concrete, shotcrete is able to minimize or eliminate the need for use of formwork required for conventional concrete construction.
b) Shotcrete is compacted at high impact velocity, and can achieve increased compaction compared to cast-in-place concrete.
c) Shotcrete is one of the major construction methods for repair and rehabilitation of concrete structures, especially where the use of formwork and access are challenging. With infrastructure aging, more and more shotcrete is being used for structural repair and rehabilitation and seismic upgrades.
d) In underground applications in tunnels and mines, shotcrete has proven to be a cost effective and safe method of ground support.

With the increasing usage of shotcrete, questions have been raised with regards to the long term performance and durability of shotcrete. One of the challenges presently facing the shotcrete industry across North America is the question of: *how does the durability of shotcrete compare to that of cast-in-place concrete*? This question has been asked by owners, structural engineers, architects, equipment and materials suppliers. In particular some owners, such as transportation agencies across Canada and the US, have raised this question and this caused some difficulties for shotcrete materials suppliers, contractors and engineers in responding to this question. This difficulty is primarily caused by a lack of adequate comparative data about the basic durability of shotcrete compared to cast-in-place concrete.

Durability is the long-term performance of concrete structures and includes factors such as: resistance to weathering, corrosion, chemical attack, alkali aggregate reaction, carbonation and freeze-thaw deterioration. All of these factors are influenced by the transport properties of the concrete or shotcrete during the service life of the structure. Hence the importance of developing a fundamental understanding of the comparative transport properties of shotcrete compared to conventional cast-in-place concrete. This study is aimed at this objective.

The present research data can be used to provide a comparative statement regarding the expected durability and predicted service life of structures made with these different materials/systems. The effect of different cementing materials in the mixtures, such as cement, fly ash and silica fume, on transport properties is studied. The paper presented here is part of a larger research program and the other parts of the research study will be published separately.

2.0 EXPERIMENTAL PROGRAM

2.1 Mix Designs and Materials

Measurement of the transport properties in this study was based on tests conducted to:

- ASTM C642: Density, boiled absorption and volume of permeable voids. This test method is widely used as a qualification and quality control testing method in the shotcrete industry.
- ASTM C1202: Electrical indication of concretes ability to resist chloride ion penetration. This test method is frequently used as a qualification method to qualify the shotcrete or concrete mixture. However, the test itself is controversial in that it measures current flow in Coulombs (1 Coulomb=1 amp in 1 sec) which in turn can be related to electrical resistivity (Ω=V/A), rather than actual chloride penetration.

Cast-in-place concrete mixtures, cast shotcrete mixtures and shot shotcrete mixtures were all tested with all the above listed test methods. The inclusion of fly ash or silica fume was conducted to represent mixtures commonly used in industry.

Detailed as-batched mixture proportions are provided in Tables 1 and 2 which follow. All mixes were dry-batched by the same supplier from Vancouver, Canada and provided as pre-bagged materials in bulk bin bags. Mixes of cast concretes (A1, B1, C1), cast wet-mix shotcretes (A2, B2, C2), shot wet-mix shotcretes (A3, B3, C3), and shot wet-mix shotcretes with 5% accelerator (A4, B4, C4) all have the same water:cementitious ratio (W/CM) of 0.40. All mixes used aggregates conforming to the ACI 506 Gradation No. 2 requirements. A high range water reducing admixture was used for wet-mix shotcretes at the dosages needed to produce the required slump at a 0.40 W/CM ratio.

Such concretes and shotcretes would satisfy the CSA A23.1 Table 2 requirements for a C-1 exposure condition (i.e., structurally reinforced concrete exposed to chlorides with a maximum water/cementing material ratio of 0.40 and minimum 56 day compressive strength of 35 MPa). Additional air entrainment would be required for use of such concrete or shotcrete in a freezing and thawing exposure environment.

Table 1: As-Batched Wet-Mix Shotcrete Mixture Proportions

Mix. No.	Mix Description	Placement Method	Mix I.D.	As-Batched Mixture Proportions for 1.0 m^3								
				Cement (Type GU) (kg)	Fly Ash (kg)	Silica Fume (kg)	Coarse Aggregate (10-5 mm, SSD) (kg)	Fine Aggregate, SSD (kg)	Water (L)	High Range Water Reducing Admxiture (L)	Total Mass (kg)	w/cm ratio
A1	Portland Cement	Cast Concrete	C-Cast	415	0	0	1027	691	168	0	2329	0.40
A2	Portland Cement	Cast Wet-Mix	C-Wet-Mix-Cast	439	0	0	419	1256	177	0.525	2291	0.40
A3	Portland Cement	Shot Wet-Mix	C-Wet-Mix-Shot	445	0	0	425	1273	179	0.533	2322	0.40
A5	Portland Cement	Shot Wet-Mix 5% Accelerator	C-Wet-Mix-Shot-5%	443	0	0	423	1267	179	0.530	2313	0.40
B1	Fly Ash Modified	Cast Concrete	FA-Cast	334	79	0	1023	688	166	0	2319	0.40
B2	Fly Ash Modified	Cast Wet-Mix	FA-Wet-Mix-Cast	343	85	0	409	1224	173	0.622	2233	0.40
B3	Fly Ash Modified	Shot Wet-Mix	FA-Wet-Mix-Shot	351	86	0	418	1252	176	0	2284	0.40
B5	Fly Ash Modified	Shot Wet-Mix 5% Accelerator	FA-Wet-Mix-Shot-5%	349	86	0	416	1246	176	0.633	2274	0.40
C1	Silica Fume Modified	Cast Concrete	SF-Cast	379	0	34	1005	676	166	0.585	2263	0.40
C2	Silica Fume Modified	Cast Wet-Mix	SF-Wet-Mix-Cast	395	0	38	414	1239	175	1.259	2262	0.40
C3	Silica Fume Modified	Shot Wet-Mix	SF-Wet-Mix-Shot	404	0	39	422	1265	178	1.285	2310	0.40
C5	Silica Fume Modified	Shot Wet-Mix 5% Accelerator	SF-Wet-Mix-Shot-5%	400	0	38	418	1253	177	2.036	2287	0.40

N/A = Not Applicable

Table 2. As-batched Mixture Design for Cast Concrete

Mix. No.	Mix Description	Mix I.D.	Mixture Proportions for 1.0 m^3									
			Cement (Type GU) (kg)	Fly Ash (Class F) (kg)	Silica Fume (kg)	Coarse Aggregate (10-5 mm) SSD (kg)	Fine Aggregate SSD (kg)	Water (L)	Water Reducing Admxiture (L)	w/cm ratio	Total Mass (kg)	Air content at pump (%)
A1	Portland Cement	C-Cast	415	0	0	1027	691	168	0	0.40	2329	5.50%
B1	Fly Ash Modified	FA-Cast	334	79	0	1023	688	166	0	0.40	2319	5.30%
C1	Silica Fume Modified	SF-Cast	379	0	34	1003	671	167	0.538	0.40	2263	7.20%

2.2 Batching, Mixing and Production

- Cast-in-place concrete mixes A1, B1 and C1 were hand cast in the laboratory and are described as Cast Concrete. Test panels for mixtures A1, B1 and C1 were cast in the laboratory with sufficient vibration to achieve full compaction.
- Wet-mix shotcrete mixes A2, B2 and C2 were mixed and cast in the field. Test panels for mixtures A2, B2, C2, were cast manually with sufficient vibration to achieve full compaction.
- Mixes A3, B3 and C3 were shot in the field (see Figures 1 & 2).

- Wet-mix shotcrete mixes A4, B4 and C4 were shot with 5% accelerator (non-alkaline) added at the nozzle during shooting.
- Wet-mix shotcrete was dry-batched and supplied in 1 cu.yd bulk bin bags. It was discharged and mixed in a pan mixer with a batch size of 1 cu.yd. Water and the high range water reducing admixture were dosed and added manually. The wet-mix shotcrete pump was typical of that used in the shotcrete industry and conformed to ACI 506 requirements.
- An ACI certified nozzlemen, (certified for wet-mix overhead and vertical processes), conducted the shooting.
- Rebound and overspray were controlled properly. The nozzleman controlled the nozzle angle, nozzle distance and air flow from the air compressor, as required by ACI 506. It is estimated that about 4-6% rebound occurred with the wet-mix process.

In summary, the shotcrete application met ACI 506 requirements and was representative of proper application. The mixing and shooting were conducted at LZhang's laboratory in Vancouver, Canada in October, 2013.

Figure 1: Concrete pan mixer and wet-mix shotcrete pump. After mixing, shotcrete was discharged into the shotcrete pump.

Figure 2: Shotcrete Test Panels were shot by an ACI certified shotcrete nozzleman.

On-site monitoring of concrete and shotcrete batching, mixing and test panel production was provided by experienced shotcrete engineers. Testing for plastic properties of the concrete and shotcrete was provided by an ACI certified concrete testing technician.

The following basic concrete and shotcrete testing program was conducted:

Table 3. Field and Laboratory Tests

Basic Concrete and Shotcrete Properties	**Test Method**
Slump	ASTM C143
Air Content, at pump and as shot	ASTM C231
Shotcrete and Ambient Temperatures	ASTM C138
Compressive Strength at 7 & 28 Days	ASTM C1604
Transport Properties	
Density, Boiled Absorption & Volume of Permeable Voids at 28 days	ASTM C642
Rapid Chloride Penetrability Testing at 90 days	ASTM C1202

3.0 BASIC CONCRETE AND SHOTCRETE TEST RESULTS AND DISCUSSION

3.1 Fresh properties

Plastic properties of shotcrete were tested to ACI 506 requirements and are summarized in Table 4.

The air content for as-batched shotcrete and as-shot shotcrete were tested separately. The as-batched air content was tested on samples from the shotcrete pump. The as-shot air content was tested on samples extracted from the in-situ shotcrete. Slump for non-acceleratored wet-mix shotcrete ranged from 80 mm to 120 mm. For the accelerated wet-mix shotcretes, the slump was increased to the 180 to 220 mm slump range, to allow for proper dispersion of the accelerator at the nozzle, as is standard industry practice. This increase in slump was achieved by increasing the high range water reducing admixture dosage, with no increase in the water/cementing materials ratio.

Table 4. Fresh Concrete and Shotcrete Properties

<table>
<tr><th>Mix No.</th><th>Mix Description</th><th>Placement Method</th><th>Mix I.D.</th><th>Air content, % (as batched)</th><th>Air content, % (as-shot)</th><th>Slump (mm)</th><th>Initial Set</th><th>Final Set</th><th>Shotcrete Temperature (°C)</th><th>Air Temperature (°C)</th></tr>
<tr><td>A1</td><td>Portland Cement</td><td>Cast Concrete</td><td>C-Cast</td><td>5.5%</td><td>Not Applicable</td><td>85</td><td rowspan="3" colspan="2">Not available</td><td>21</td><td>19</td></tr>
<tr><td>A2</td><td>Portland Cement</td><td>Cast Wet-Mix</td><td>C-Wet-Mix-Cast</td><td>4.5%</td><td>Not Applicable</td><td>120</td><td>15</td><td>7</td></tr>
<tr><td>A3</td><td>Portland Cement</td><td>Shot Wet-Mix</td><td>C-Wet-Mix-Shot</td><td>4.5%</td><td>3.2%</td><td>120</td><td>15</td><td>7</td></tr>
<tr><td>A5</td><td>Portland Cement</td><td>Shot Wet-Mix 5% Accelerator</td><td>C-Wet-Mix-Shot-5%</td><td>5.9%</td><td>3.6%</td><td>190</td><td>12 mins</td><td>1 hr 20 mins</td><td>14</td><td>9</td></tr>
<tr><td>B1</td><td>Fly Ash Modified</td><td>Cast Concrete</td><td>FA-Cast</td><td>5.3%</td><td>Not Applicable</td><td>155</td><td rowspan="2" colspan="2">Not available</td><td>21</td><td>19</td></tr>
<tr><td>B2</td><td>Fly Ash Modified</td><td>Cast Wet-Mix</td><td>FA-Wet-Mix-Cast</td><td>5.6%</td><td>Not Applicable</td><td>180</td><td>Not available</td><td>8</td></tr>
</table>

B3	Fly Ash Modified	Shot Wet-Mix	FA-Wet-Mix-Shot	5.4%	3.5%	80			14	7
B5	Fly Ash Modified	Shot Wet-Mix 5% Accelerator	FA-Wet-Mix-Shot-5%	5.6%	3.9%	180	32 mins	2 hrs	13	8
C1	Silica Fume Modified	Cast Concrete	SF-Cast	7.2%	Not Applicable	40			22	19
C2	Silica Fume Modified	Cast Wet-Mix	SF-Wet-Mix-Cast	5.1%	Not Applicable	100			14	7
C3	Silica Fume Modified	Shot Wet-Mix	SF-Wet-Mix-Shot	5.1%	3.4%	100	Not available		15	7
C5	Silica Fume Modified	Shot Wet-Mix 5% Accelerator	SF-Wet-Mix-Shot-5%	6.6%	4.0%	220	10 mins	1 hr 15 mins	13	8

3.2 Compressive strength

For each mix, a minimum of two cores were extracted and tested for compressive strength at 7 days, and three cores were extracted and tested for compressive strength at 28 days. Test results are listed in Table 5. 28 day test results are plotted in Figure 3.

Table 5. Compressive Strength

Mix No.	Mix Description	Placement Method	Mix I.D.	7 Days Compressive Strength	28 Days Compressive Strength
				MPa	MPa
A1	Portland Cement	Cast Concrete	C-Cast	37.2	46.5
B1	Fly Ash Modified	Cast Concrete	FA-Cast	36.6	48.8
C1	Silica Fume Modified	Cast Concrete	SF-Cast	32.8	39.4
A2	Portland Cement	Cast Wet-Mix Shotcrete	C-Wet Mix-Cast	32.5	40.4
B2	Fly Ash Modified	Cast Wet-Mix Shotcrete	FA-Wet Mix-Cast	29.3	39.3
C2	Silica Fume Modified	Cast Wet-Mix Shotcrete	SF-Wet Mix-Cast	33.7	45.1
A3	Portland Cement	Shot Wet-Mix Shotcrete	C-Wet Mix-Shot	38.5	47.1
B3	Fly Ash Modified	Shot Wet-Mix Shotcrete	FA-Wet Mix-Shot	39.7	44.9
C3	Silica Fume Modified	Shot Wet-Mix Shotcrete	SF-Wet Mix-Shot	38.1	51.5
A4	Portland Cement	Shot Wet-Mix Shotcrete with 5% Accelerator	C-Wet Mix-Shot-5%	31.5	49.9
B4	Fly Ash Modified	Shot Wet-Mix Shotcrete with 5% Accelerator	FA-Wet Mix-Shot-5%	37.5	41.9
C4	Silica Fume Modified	Shot Wet-Mix Shotcrete with 5% Accelerator	SF-Wet Mix-Shot-5%	29.4	38.1

The compressive strength at 28 days for cast concretes and wet-mix shotcretes, including results from both cast and shot processes ranged between 38.1 and 51.5 MPa.

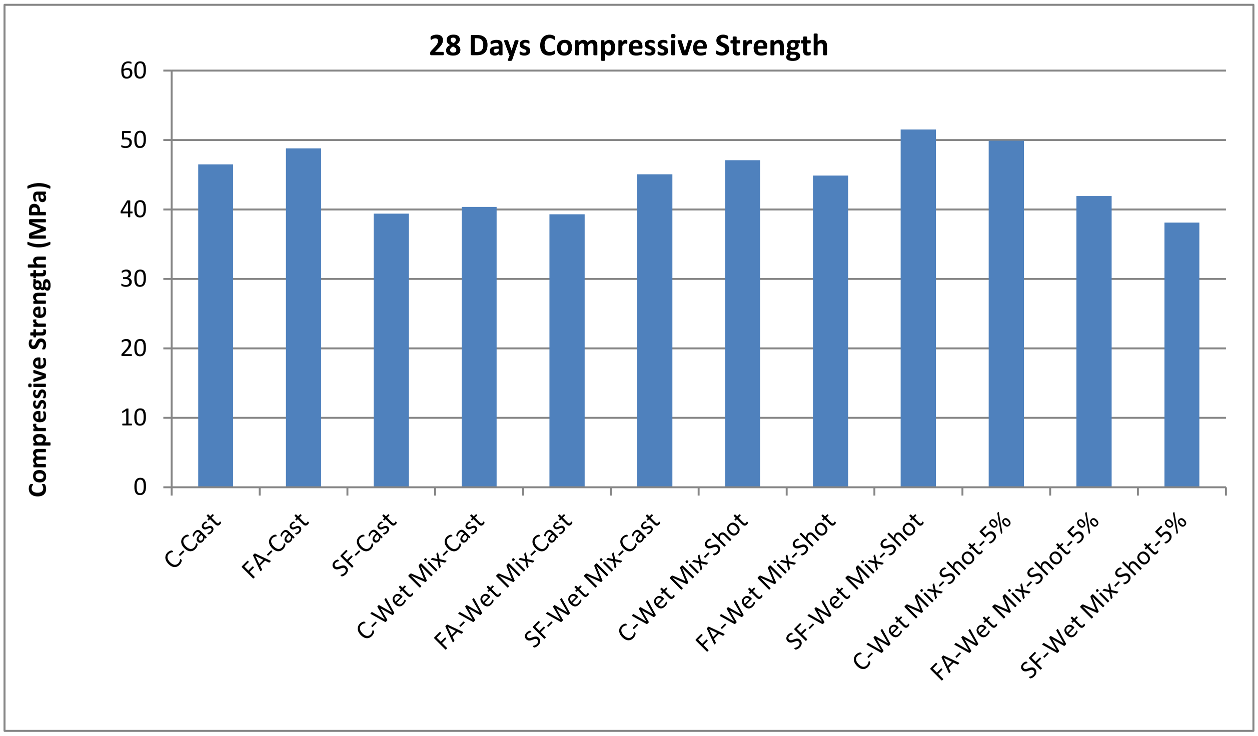

Fig. 3 28 day compressive strength

Compressive strength of shot wet-mix shotcrete vs. cast wet-mix shotcrete and cast concrete

If one compares like mixes (e.g., cement only mixes with cast concrete, cast wet-mix shotcrete and shot wet-mix shotcrete) and the same for fly ash and silica fume mixes, then it is evident that:

Shot shotcrete mixes without accelerators consistently (with the single exception of mix B3) produce higher 7 & 28 day compressive strengths compared to cast shotcrete mixes, or cast concrete mixes. The differences are not large, but they are consistent. This supports the statement that *"shotcrete, when properly applied, provides superior compaction to the cast-in-place concrete process"*.

Table 6. Compressive Strength Shot vs. Cast Shotcrete

Compressive Strength	Cast Concrete (MPa)	Cast Wet-Mix Shotcrete (MPa)	Shot Wet-Mix Shotcrete (MPa)	Increase of strength from SHOT vs. CAST Shotcrete	Shot Wet-Mix Shotcrete with 5% Accelerator (MPa)	Increase of strength from SHOT with 5% Accelerator vs. CAST Shotcrete
Cement	46.5	40.4	47.1	17%	49.9	24%
Fly Ash	48.8	39.3	44.9	14%	41.9	7%
Silica Fume	39.4	45.1	51.5	14%	38.1	-16%

Compressive strength of cement vs. fly ash vs. silica fume

The average compressive strength for both cast and shot wet-mix shotcrete at 7 & 28 days was similar for mixes with cement only and mixes with fly ash, but higher in mixes with silica fume. The 28 days compressive strength for cast concrete with silica fume was lower than that with cast concrete with fly ash and cement only. This is attributed to the higher air content in the cast silica fume mix. This was later found not to adversely affect the transport properties for the silica fume mix, even when accelerator was added.

Effect of accelerator on wet-mix compressive strength

The addition of accelerator is a common practice in the shotcrete industry, in particular, in underground shotcrete application. Accelerators help shotcrete stick overhead and early age compressive strength development. However, they tend to reduce the 28 days compressive strength depending on the accelerator addition rate. With 5% by mass of cement of non-alkali accelerator added to the wet-mix shotcrete, the compressive strength for the cement, fly ash, and silica fume mixes decreased relative to the mixtures with no accelerator. This is as expected. It is, however, worth noting that all the accelerated shotcrete mixes readily satisfied the CSA A23.1 Class C-1 compressive strength requirement of a minimum 35 MPa at 28 days.

3.3 Boiled Absorption and Volume of Permeable Voids (BA & VPV)

BA and VPV test were conducted to evaluate the porosity of the concrete and shotcrete. Test results from cores tested at 28 days are plotted in Fig. 4.

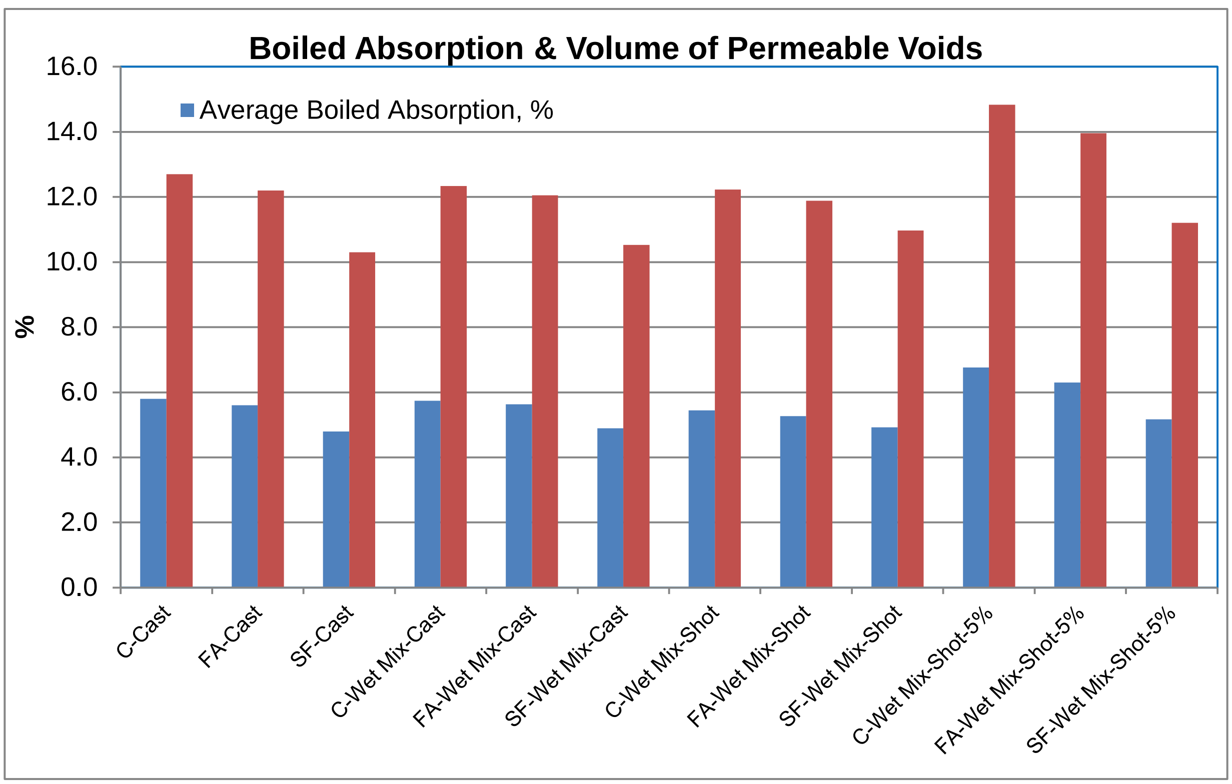

Fig. 4 Test Results for Boiled Absorption and Volume of Permeable Voids

ACI 506 recommends that values for BA and VPV not exceed 8% for BA and 17% for VPV. All of the 18 mixtures tested produced BA values less than 6.5% and VPV values less than 14.5%.

Test results for both BA and VPV consistently decreased from cement, to fly ash to silica fume irrespective of the placement method. This is consistent with the results of previous research conducted in North America, Australia, South Africa and Europe (Ref 1).

Table 8 summarizes the BA and VPV results for shot wet-mix shotcrete vs. cast wet-mix shotcrete vs. cast concrete. Cast concrete mixtures have almost the same BA and VPV values as of cast wet-mix shotcrete. This is because the W/CM ratio for both groups of mixtures is the same.

Table 8. BA and VPV for shot wet-mix shotcrete vs. cast wet-mix shotcrete

Boiled Absorption	Cast Wet-Mix Shotcrete (%)	Shot Wet-Mix Shotcrete (%)	Decrease from Shot vs. Cast	Shot Wet-Mix Shotcrete with 5% Accelerator	Increase from Shot with 5% Accelerator vs. Cast
Cement	5.7	5.4	5%	6.8	19%
Fly Ash	5.6	5.3	5%	6.3	13%
Silica Fume	4.9	4.9	0%	5.2	6%
Volume of Permeable Voids	Cast Wet-Mix Shotcrete	Shot Wet-Mix Shotcrete	Decrease from Shot vs. Cast	Shot Wet-Mix Shotcrete with 5% Accelerator	Increase from Shot with 5% Accelerator vs. Cast
Cement	12.3	12.2	1%	14.8	20%
Fly Ash	12	11.9	1%	14	17%
Silica Fume	10.5	11.0	-5%	11.2	7%

BA and VPV test results for shot wet-mix shotcretes without accelerator are slightly lower than for cast wet-mix shotcretes for the cement and fly ash mixtures, and equal or slightly higher for cast wet-mix shotcrete with silica fume. This indicates that overall the shooting process tends to produce lower permeability than the casting process. However, BA and VPV test results for the shot wet-mix shotcretes with 5% accelerator are higher than for the shot wet-mix shotcrete without accelerator, or the cast wet-mix shotcrete. This is as expected.

Table 9. BA and VPV for shot wet-mix vs. cast concrete

Boiled Absorption	Cast Concrete, %	Shot Wet-Mix Shotcrete, %	Increase from SHOT Wet-Mix vs. CAST Concrete
Cement	5.8	5.4	-7%
Fly Ash	5.6	5.3	-5%
Silica Fume	4.8	4.9	2%
Volume of Permeable Voids	Cast Concrete	Shot Wet-Mix Shotcrete	Increase from SHOT Wet-Mix vs. CAST Concrete
Cement	12.7	12.2	-4%
Fly Ash	12.2	11.9	-2%
Silica Fume	10.3	11.0	7%

Table 9 summarizes the comparison of BA and VPV values for shotcrete vs. wet-mix shotcrete vs. cast concrete. It shows that BA and VPV values for the wet-mix shotcrete process decrease for the cement and fly ash mixes and are similar for the silica fume mix for non-accelerated shotcretes compared to equivalent cast concrete mixes. By contrast, all the wet-mix shotcretes with 5% accelerator have higher BA and VPV values than the equivalent cast concrete mixes. However, these values are all well below the ACI 506R acceptable values for BA and VPV.

3.4 Rapid Chloride Penetration Resistance (RCPT)

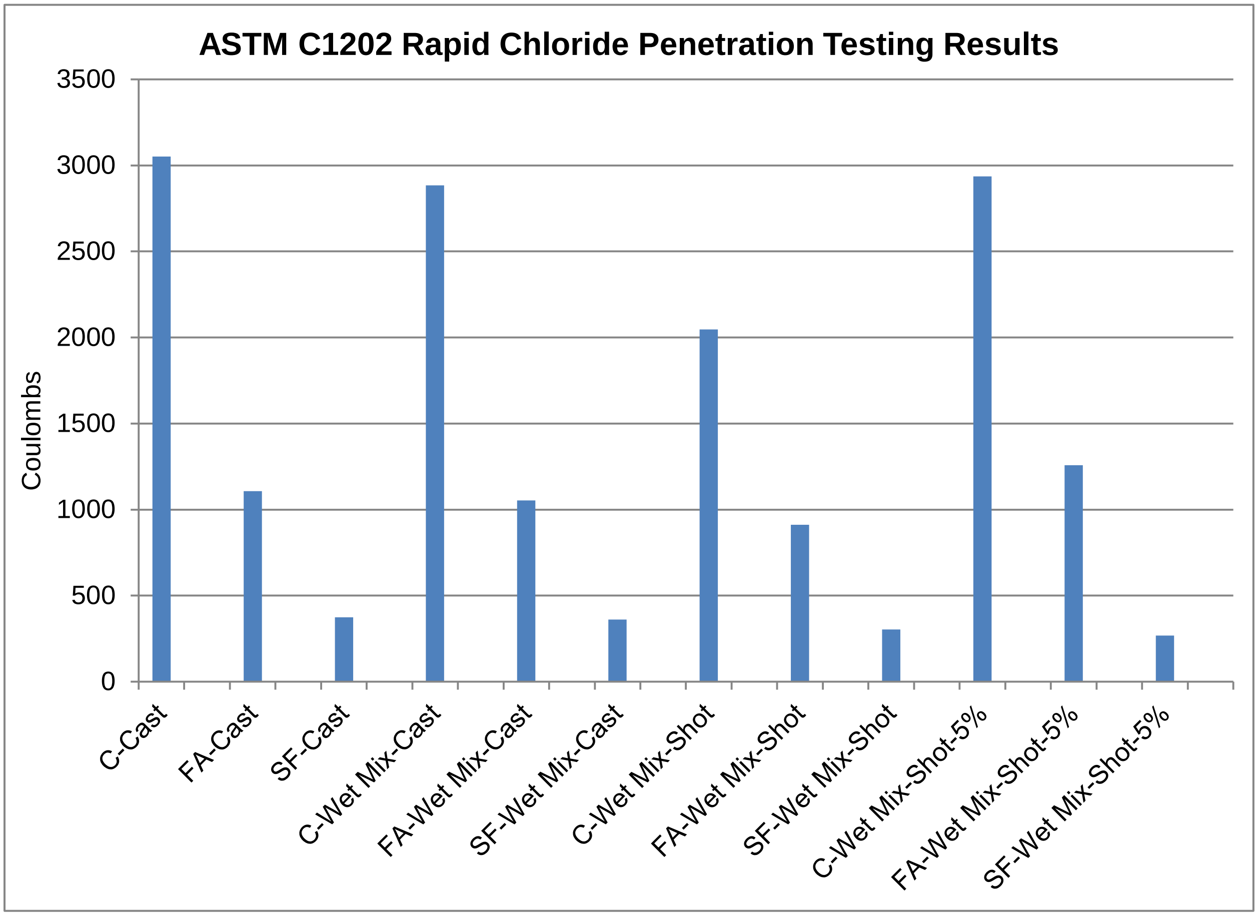

Fig 4. Rapid Chloride Penetration Resistance for shotcrete vs cast concrete

The ASTM C1202 rapid chloride penetration (RCP) test is one of the most widely used test methods to evaluate the chloride penetration resistance of concrete. Although the RCP test provides a measure of current flow, rather than the chloride ion diffusion rate or actual chloride penetration resistance, it does provide information on how the concrete affects electrical resistivity.

Table 10. RCP Results (Coulombs)

	Cast Concrete	Cast Wet-Mix Shotcrete	Shot Wet-Mix Shotcrete	Shot Wet-Mix Shotcrete with 5% Accelerator
Cement ONLY	3052	2884	2047	2937
Fly Ash + Cement	1108	1054	912	1259
Silica Fume + Cement	374	361	305	269

Cast concrete vs cast wet-mix shotcrete vs shot wet-mix

The RCP results for cast concrete and cast wet-mix shotcrete are very similar for each of the cement, fly ash and silica fume mixtures. However, RCP results for the shot wet-mix shotcretes are consistently lower than for comparable cast concrete and cast shotcrete mixtures. When 5% accelerator is added, the RCP results for shot wet-mix shotcrete increase for the cement only and fly ash mixes, but are similar for the silica fume mix. The wet-mix shotcrete with 5% accelerator has similar RCP results to the cast concrete and cast shotcrete mixes.

Table 11. CSA A23.1/A23.2-14 RCP Performance Requirement

Charged Passed (Coulombs)	Chloride Ion Penetrability
>4,000	High
2,000-4,000	Moderate
1,000-2,000	Low
100-1,000	Very Low
<100	Negligible

Cement vs. Fly Ash vs. Silica fume

Mixtures with cement ONLY produced the highest RCP results with values in the 1582 to 3052 Coulombs range and according to Table 11 above, the Chloride ion penetrability is considered as moderate. Mixes with fly ash produced RCP results in the range of 637 to 1259 Coulombs and the chloride ion penetrability is considered to be Low to Very Low. Mixes with silica fume produces RCP results in the range of 250 to 374 Coulombs and the chloride ion penetrability is considered to be Very Low. Therefore, it is obvious that the addition of fly ash and silica fume reduce the Coulombs rating substantially. The incorporation of silica fume in the mix is the most efficient way to markedly reduce the Coulomb rating and hence chloride ion penetrability.

Conclusions

1) All transport properties tested show consistently that the porosity decreases from mixtures with cement only, to fly ash, to silica fume. This is consistent with the general understanding of effect of supplementary cementitious materials which involves pozzolanic reactions which refine the pore structure of the matrix, thus reducing permeability and enhancing durability.
2) All transport properties show that the shotcrete process, including mixes of shot wet-mix shotcrete with and without accelerator have transport properties that are close to, or even better than that of cast shotcrete and cast-in-place concrete. This provides factual evidence that the

shotcrete process, when applied properly, is able to provide a matrix that has the same, or even better, transport properties compared to the cast concrete process.

3) All of these improved transport properties, including reduced boiled absorption and volume of permeable voids, and reduced rapid chloride penetration resistance lead to reduced porosity for the samples from the shotcrete process. The lower porosity leads to a lower coefficient of diffusion of chloride, which means that it will take a longer time for Cl- to diffuse to the depth of the reinforcement. Therefore, the matrix is more protective and results in a more durable structure

In summary, the results of this comparative study of the basic and transport properties of wet-mix shotcrete compared to cast concrete, demonstrates that properly applied shotcrete can provide equivalent or superior durability performance to cast-in-place concrete for like mixtures.

Acknowledgement

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