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Evaluation of NForce-Fiber

in Field Application of Wet-Mix Shotcrete

Submitted to:

CANADIAN GREENFIELD TECHNOLOGIES CORP.

Submitted by:

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Victoria, BC

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1.0 INTRODUCTION

D.R. Morgan, Ph.D., P.Eng., FACI, Consulting Engineer, was retained by Canadian Greenfield Technologies Corp. (CGTC) to conduct a field evaluation of the performance of NForce-Fiber in a Structural Shotcrete application, using the Wet-Mix Shotcrete process. This field evaluation was carried out at the Jos. J. Albanese Inc. yard in Santa Clara, California on November 7, 2016. This field evaluation was a follow up to a laboratory investigation previously conducted in Vancouver, BC, Canada, for CGTC by LZhang Consulting & Testing Ltd. and presented in a report titled *Evaluation of NForce-Fiber in Wet-Mix Shotcrete*, June 8, 2016. (Ref.1). Dr. Morgan participated in this previous laboratory study, which utilized pre-batched dry materials supplied in 0.5 cubic meter bulk bin bags. The dry materials were discharged into a precast concrete type pan mixer with counter-rotating paddles, with the mix water and loose NForce-Fiber added by hand. The fibers dispersed well throughout the mix with this production system and pumped and shot well with no fiber balls, plugs, or segregation in the shotcrete mix.

The main purpose of the field evaluation study detailed in this report was to assess the performance of NForce-Fiber supplied in one-pound shreddable bags added to standard ready mix concrete trucks during wet-mix shotcrete batching, mixing and supply on subsequent shotcrete pumping, shooting and finishing. This report details the findings of this field evaluation, in which the fiber-reinforced shotcrete was used to construct two structural shotcrete walls for aggregate storage bins in the Jos.J. Albanese yard.

2.0 WET-MIX SHOTCRETE MIXTURE DESIGNS

Two different shotcrete mixture designs were utilized in this field evaluation. They were both batched, mixed and supplied by Central Concrete Supply Company, a division of U.S. Concrete Company. The base shotcrete mixture designs were typical of wet-mix shotcretes typically used in the San Jose/Santa Clara region of California. Both mixes had the same cement content and contained 15% fly ash (by mass of cement). The main differences between them were that the first mix shot, (Mix A), had a 3/8in (10mm) pea gravel type coarse aggregate and an NForce-Fiber addition rate of 1.5 lb/cu.yd. (0.89 kg/ cu.m.), whereas the second mix shot, (Mix B), had a crushed ½ in. (13 mm) granite coarse aggregate and an NForce-Fiber addition rate of 3.0 lb/cu.yd. (1.78 kg/cu.m.).

3.0 EQUIPMENT

Fig.1 shows the ready-mix concrete truck used to supply the second load of shotcrete (Mix B). Fig. 2 shows the fiber reinforced wet-mix shotcrete discharging from the truck chute into the pump hopper. Note the highly cohesive nature of the shotcrete. Fig. 3 shows the Reed C50 pump used to pump the shotcrete to the nozzle, where compressed air was added to pneumatically apply the shotcrete to the receiving surface.

Fig.1 Ready-mix concrete truck used for mixing and supply of fiber-reinforced shotcrete

Fig.2 Discharge of fiber-reinforced shotcrete into pump hopper

Fig.3 Reed C50 pump used to pump shotcrete

4.0 STRUCTURAL SHOTCRETE WALLS

Two structural shotcrete walls, one L-shaped and the other straight, were formed and shot. Braced, single-sided plywood formwork was erected. The L-shaped wall was about 16 ft. (4.9 m) long and 6ft. (1.8 m) high. The straight wall was about 20ft. (6.1 m) long and ranged in height from about 4 to 5 ft. (1.2 to 1.5 m). Both walls were 18 in. (460 mm) thick and were reinforced with a double mat of No.6 (20M) rebar as shown in Figs. 4 and 5.

Fig.4 Formwork and rebar for straight structural shotcrete wall

Fig.5 Formwork and rebar for L-shaped shotcrete wall

The walls were constructed as extensions to aggregate storage bins and provided a good opportunity to evaluate how the NForce-Fiber reinforced shotcrete behaved during shotcrete application and finishing.

5.0 SHOTCRETE PRODUCTION

5.1 Shotcrete Batching, Mixing and Supply

An 8.0 cu. yd. (6.1 cu.m.) load of Mix A was supplied at a slump of 3.5 in (90 mm) and a 7.0 cu.yd. (5.4 cu.m.) load of Mix B was supplied at a slump of 3.0 in. (75 mm). The shotcrete temperature for both mixes was 76F (24C) and the ambient temperature was around 72F (22C). The time from batching to completion of discharge was 2.0 hours for Mix A and 1 hour: 15 mins for Mix B.

5.2 Shotcrete Pumping and Shooting

The shotcrete pumped and shot well with no fiber balls, mix segregation, or pump blockages during shooting. The fibers were observed to be well dispersed throughout the mix and no remnants of the shredded fiber bags were observed in the mix during discharge into the pump, or during shooting. The shotcrete was observed to be very cohesive and the nozzleman was able to bench-gun shoot (stack) the structural shotcrete to its full height in both walls, without any sagging, sloughing or fall-out. The shotcrete was applied to just cover the outer layer of rebar. A blow-pipe operator worked alongside the nozzleman, blowing out any accumulations of rebound and/or overspray from the areas about to receive shotcrete. A finish coat of the *covercrete* shotcrete was then applied from the top down to build the walls out the full thickness. Figs. 6 and 7 show the shotcrete application in progress on the two different walls.

Fig.6 Shotcrete application on straight wall

Fig.7 Shotcrete application on L-shaped wall

5.3 Shotcrete Finishing

Shooting wires had been installed to control line and grade. The nozzleman shot to just cover the shooting wires. Because of the very cohesive characteristics of the fiber reinforced shotcrete, the finisher operating the cutting screed (rod) was able to follow

immediately behind the nozzzleman (only a few feet away), trimming the shotcrete to the shooting wires to control line and grade, as shown in Fig. 8.

Fig.8 Trimming shotcrete to shooting wires in straight wall with cutting screed (rod)

Fig. 9 Finishing of L-Shaped Wall

The finisher with the wood derby (long wood float) followed right behind, closing and smoothing the shotcrete surface. Final finishing with a wood hand float was provided to

provide a stucco-like finish appearance. Fig. 9 shows finishing of the L-shaped wall. Fig.10 shows a view of the final finished straight wall.

Fig.10 View of finished straight wall

Fig.11 Stripped face of L-shaped wall

6.0 SHOTCRETE TESTING

A few days after shooting the plywood panels were stripped from the aggregate bin walls and the stripped face of the walls examined. The walls were observed to be essentially defect free. There were no significant voids of incomplete consolidation, sags or tears, or shadows behind rebar. Fig.11 shows the stripped back face of the high L-shaped wall.
In addition to shooting the structural walls, the nozzleman shot a 2ft. x2 ft. x 4in. thick (610mm x 610mm x 100mm thick) test panel with Mix A. This test panel was cured on site until shipment to the LZhang Consulting and Testing laboratory in Vancouver, BC, for testing. Cores were extracted at 21 and 28 days for testing for compressive strength to ASTM C1604 and Boiled Absorption and Volume of Permeable Voids to ASTM C642. Test reports are provided in Appendix A.

The average shotcrete compressive strength at 28 days was 4446 psi (30.7 MPa), which satisfied the specified minimum compressive strength requirement of 4000 psi (27.6 MPa) at 28 days. The average values for Boiled Absorption and Volume of Permeable Voids at 28 days were 7.6% and 16.9% respectively. These test results satisfied the ACI 506 recommended maximum allowable values of 8% for Boiled Absorption and 17% for Volume of Permeable Voids for durable shotcrete.

7.0 DISCUSSION

NForce-Fiber is a natural hemp-based fiber which is used in lieu of polymer-based microsynthetic fibers in concrete and wet-mix shotcrete, primarily for the purpose of control of plastic and drying shrinkage cracking. In the LZhang Consulting & Testing Ltd. laboratory study (Ref.1) of a comparative evaluation of the efficacy of NForce-Fiber and a microsynthetic fiber (at equal fiber volume additions) it was demonstrated that the NForce-Fiber was more effective in mitigating plastic and drying shrinkage cracking than the microsynthetic fiber. In the laboratory study a number of other beneficial attributes were found when using the NForce-Fiber , compared to a plain control shotcrete without fibers, or mixes with microsynthetic fibers. These included enhanced adhesion and cohesion of the wet-mix shotcrete, with consequent improved bench-gun shooting and stacking ability, and improved resistance to sagging, sloughing and fall-out. The mixes with NForce-Fiber also demonstrated superior finishing ability, being easier to rod, trowel and finish without sags or tears, and no protruding fibers in the surface finish. The NForce-Fiber appeared to act as a *finishing aid.*

As previously mentioned, the laboratory study referred to was based on the use of dry, prebagged shotcrete materials, mixed with water and loose fibers, in a pan mixer with counter-rotating paddles. The prime purpose of this field evaluation study was to assess the behaviour of wet-mix shotcrete in a full scale field trial when using ready-mix concrete batching, mixing and supply, with the NForce-Fiber being added in one-pound (454 gram) shreddable bags during batching at the ready-mix batch plant. The results of this field evaluation study are described in the previous sections in this report and are summarized in the Conclusions which follow.

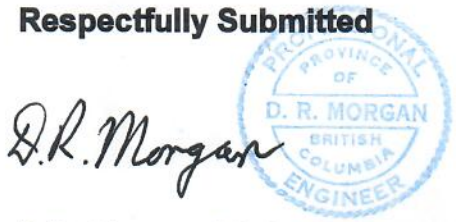
8.0 CONCLUSIONS

In this field evaluation of the behavior of wet-mix shotcrete batched, mixed and supplied using ready-mix concrete trucks, with NForce-Fiber added to the trucks at the batch plant in one pound (454gram) shreddable bags, it was demonstrated that:

1. The NForce-Fiber, added at addition rates of 1.5 lb/cu.yd (0.89 kg/cu.m.) and 3.0 lb./cu.yd. (1.78 kg/cu.m.) was readily able to be mixed and dispersed throughout the shotcrete load. No balls or clumps of fiber, or remnants of the shreddable bags were observed coming down the ready-mix concrete truck chute, at discharge into the pump hopper, or during shooting. The mixes appeared very cohesive, with uniform fiber dispersion. (See Fig.2).
2. The mixes pumped and shot well, with no evidence of segregation, or pump blockages.
3. The nozzleman was able to bench-gun shoot and stack the structural shotcrete walls to their full height in a single pass, without sagging, sloughing or shotcrete fall-out. (See Fig. 7). The nozzleman and shotcrete crew were impressed with the great adhesion and cohesion and general shooting characteristics of the mixes, particularly for the mix with 3.0 lb/cu.yd. (1.78 kg/cu.m.) of NForce-Fiber.
4. After shooting to just encase the outer layer of rebar, a top-down finish coat of the same shotcrete was applied to build the walls out to their full thickness, as defined by the shooting wires. The shotcrete mixes were very easy to finish. The finisher using the cutting screed (rod) was able to follow closely behind the nozzleman and was in turn closely followed by the finisher with the derby and final finishers with wood floats. (See Fig. 8). This significantly improved productivity relative to finishing wet-mix shotcrete without fibers, or with microsynthetic fiber, in that the finishers did not have to wait for the shotcrete to stiffen considerably (in order to mitigate tendencies to sagging and sloughing if finished prematurely) before commencing finishing operations. Also, unlike mixes with microsynthetic fibers, fibers were not left protruding from the wood-float finished surface. (See Fig. 10). The finishers remarked on the superior finishing characteristics of the NForce-Fiber shotcrete.
5. The stripped faces of the structural shotcrete walls were essentially defect-free, with no sags, tears, significant voids, or shadows behind rebar (See Fig.11).
6. Cores extracted from a test panel for Mix A were tested for compressive strength and Boiled Absorption and Volume of Permeable Voids at 28 days. The average core compressive strength test result was 4446 psi (30.7 MPa), which satisfied the specified minimum compressive strength of 4000 psi (27.6 MPa) at 28 days. The average Boiled Absorption and Volume of Permeable Voids results of 7.6% and 16.9% respectively satisfied the ACI 506 recommended maximum values of 8% for Boiled Absorption and 17% for Volume of Permeable Voids for durable shotcrete.

In summary, it is considered that this Field Evaluation study (together with the previous LZhang Consulting & Testing Ltd. Laboratory study- Ref.1) has demonstrated that NForce-Fiber has many beneficial attributes for use in the wet-mix shotcrete process in structural shotcrete and other field applications.

Respectfully Submitted



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Ref.1: "Evaluation of NForce-Fiber in Wet-Mix Shotcrete", Report submitted to Canadian Greenfield Technologies Corp. by LZhang Consulting and Testing Ltd., June, 8, 2016

ACKNOWLEDGEMENTS

The support of Mr. Chris Zynda at Jos. J. Albanese Inc. and Mr. Patrick Frawley at Central Concrete Supply Company in enabling this first ever trial of the use of NForce-Fiber in a field application of wet-mix shotcrete (using ready-mix concrete batching, mixing and supply), is greatfully acknowledged.

APPENDIX A Shotcrete Test Results (Mix A)

- Compressive Strength

- Boiled Absorption and Volume of Permeable Voids

Technical Report: Compressive Strength Testing Results

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LZhang File No: 11VA062
Date: 06-Dec-16

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PROJECT: NForce-Fiber Reinforced Wet-Mix Shotcrete Evaluation: Jos. J. Albanese Yard, Santa Clara, California

SUBJECT: Materials Qualification Testing Services for Shotcrete: Compressive Strength tested to ASTM C1604

Curing: Panel was left on site and delivered to LZhang's Laboratory at 20 days, cores were extracted and moist cured in the laboratory until testing.
Specified Strength: 4000 psi (27.6 MPa) at 28 days

Mix ID	Shot Date	Test Age (days)	Load (kN)	Diameter (mm)	Compressive Strength (MPa)	Length (mm)	Length / Diameter	Corrected Compressive Strength (MPa)	Average Corrected Compressive Strength (MPa)	Average Corrected Compressive Strength (psi)
Wet-Mix Shotcrete: Mix R70138C1 with 3 lb/cu.yd NForce-Fiber	08-Nov-16	21 days	107.1	67.6	29.8	93.6	1.38	28.0	**27.3**	**3958**
			102.6	67.7	28.5	93.7	1.38	26.8		
			103.4	67.7	28.8	94.6	1.40	27.0		
		28 days	119.6	67.9	33.0	113.5	1.67	31.3	**30.7**	**4446**
			113.0	67.7	31.4	115.5	1.71	29.5		
			117.8	67.7	32.7	109.4	1.62	31.1		

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Boiled Absorption and Volume of Permeable Voids

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PROJECT: **NForce-Fiber Reinforced Wet-Mix Shotcrete Evaluation: Jos. J. Albanese Yard, Santa Clara, California**
SUBJECT: **Boiled Absorption and Volume of Permeable Voids to ASTM C 642 at 21 Days of Age**

Date Shot: 08-Nov-16
Date Tested: 29-Nov-16

Maxium BA & VPV: 8% Boiled Absorption, 17% Volume of Permeable Voids
Curing: Panel was left on site and delivered to LZhang's Laboratory at 20 days, cores were extracted and moist cured in the laboratory until testing.

Mix ID	Absorption after immersion, %	Absorption after immersion and boiling, %	Bulk density, g1 (Mg/m3)	Bulk density after immersion (Mg/m3)	Bulk density after immersion and boiling (Mg/m3)	Apparent density (Mg/m3)	Volume of permeable voids, %
Wet-Mix Shotcrete: Mix R70138C1 with 1.5 lb/cu.yd NForce-Fiber	6.8	7.6	2.231	2.384	2.400	2.684	16.9
	6.8	7.5	2.228	2.380	2.396	2.677	16.8
	6.8	7.6	2.219	2.371	2.388	2.672	17.0
Average	**6.8**	**7.6**	**2.226**	**2.378**	**2.395**	**2.678**	**16.9**

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