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Evaluation of NForce-Fiber in Wet-Mix Shotcrete

Submitted to:

CANADIAN GREENFIELD TECHNOLOGIES CORP.

Submitted by:

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Vancouver, BC

June 8, 2016

LZhang File: 11VA062 - Phase 100

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1.0 INTRODUCTION

LZhang Consulting & Testing Ltd (LZhang) was contracted by Canadian Greenfield Technologies Corp (CGT) to conduct a product evaluation for NForce-Fiber in shotcrete. The Phase I study, i.e., *"Product Study and Due Diligence Phase"* involved evaluation of the behaviour and performance of a wet-mix shotcrete made with NForce-Fiber compared to a plain wet-mix shotcrete with no fiber addition and a wet-mix shotcrete with microsynthetic fibre. The Phase I work for the wet-mix shotcrete production was conducted at the Basalite Concrete Products Ltd (Basalite) yard in Surrey, BC, on February 27, 2016. Hardened shotcrete testing was conducted at the LZhang Consulting & Testing Ltd. (LZhang) laboratories in Richmond and Vancouver, BC from February 27, 2016 up to the date when this report was prepared.

2.0 WET-MIX SHOTCRETE MIXTURE DESIGNS

The wet-mix shotcrete mixes shown in Table 1 below were evaluated in this study.

Table 1. Wet-Mix Shotcrete Mixtures

Mix Type	Shotcrete Designation	Fiber Content	
		(kg/ m^3)	(% volume)
Plain	WP	0	0
NForce-Fiber	WNF	2	0.15
Microsynthetic Fiber	WSF	1.35	0.15

The wet-mix shotcrete mixture designs for all the mixes meet the CSA A23.1/23.2-2014 Class C1 exposure requirements (Ref 1). i.e. *Structurally reinforced concrete exposed to chlorides with or without freezing and thawing conditions.* These mixes are required to have a maximum water/cementing materials ratio of 0.40, a minimum compressive strength of 35 MPa at 28 days and be suitably air entrained. The wet-mix shotcrete mixture designs for all the mxies also represent the most commonly used wet-mix shotcretes in the industry for applications such as structural shotcrete, repair and rehabilitation and shoring. The wet-mix shotcrete mix designs contain 20% fly ash by mass of cementitious materials and were based on mixes used in a comprehensive study of the transport properties of concrete and shotcrete (Ref 2). Detailed mix designs are attached in Appendix A.

3.0 PRODUCTION AND TESTING

3.1 Batching, mixing and application

A pan mixer with two sets of rotating paddles, each of which rotate in opposite directions, was used to mix the wet-mix shotcrete mixes. Materials were pre-batached in an oven-dry condition and supplied in 0.5 yd^3 bags by Basalite. All the ingredient materials, including aggregates, cement and fly ash were the same materials as those used for mixing concrete in LZhang's laboratory for a previous study of NForce-Fiber in cast concrete, conducted for Canadian Greenfield Technologies Corporation. The dry bagged materials were discharged into the pan mixer and water was added manually to the mixture which was mixed for 3 minutes. The fibers were then added and mixed for a minimum of 5 minutes. Slump was tested and superplasticizer was added when needed to achieve the required slump. The air content was tested and when in conformance with the required 5-8%, wet-mix shotcrete was then applied by an ACI certified nozzleman. Plastic shrinkage test sample panels were shot and moved to Basalite's laboratory for plastic shrinkage testing to ASTM C1579 [Ref. 3]. Test panels were shot for core extraction and testing. At two days age, beams were diamond saw cut from the test panels for flexural toughness testing (Fig. B-15 & B-16) and cores were extracted for compressive strength testing (7 & 28 days). All the beams and core samples were were cured in laboratory conditions at 23+/-2 ^{0}C, and 100% relative humidity until the age of testing. Vertical rebound testing was conducted for all the wet-mix shotcrete mixtures. Photos for the field mixing, batching, shooting and rebound testing are included in Appendix B.

3.2 Plastic Shotcrete Tests

Wet-Mix shotcrete temperature, slump and air content were tested. Test results are reported in Appendix C and are summarized in Table 2 which follows.

Table 2. Wet-Mix Shotcrete Plastic Properties

Mix	Fiber Content		Slump (mm)	Air Content (%)		Temperature (ºC)	Superplasticizer, Glenium 7100, (ml/m^3)	Air Entraining Agent (ml/m^3)
	(kg/m^3)	(% volume)		As-Batched	As-Shot			
WP	0	0	50	5.5	4.0	13.0	1150	110
WNF	2	0.15	70	9.0	4.3	18.0	1300	130
WSF	1.35	0.15	60	8.0	4.8	20.0	1050	130

It should be noted that the mix WNF has a slightly higher than specified as-batched air content. This is because the superplasticizer, Glenium 7100, was added to increase the slump to meet the minimum 50 mm slump requirement, and the superplasticizer slightly increased the air content. For wet-mix shotcrete, the as-shot air content in the in-situ shotcrete is of greater importance. The as-shot air content for all three mixes is within the specified 3.0-6.0% range. This is consistent with the requirements for air content for the shotcrete industry [Ref. 4].

3.3 Pumpability, shootability, cohesiveness, vertical thickness of build up and vertical rebound

All three wet-mix shotcrete mixtures were produced with slumps between 50-70 mm (Fig. B-11) and were found to be easily pumpable. No hose plugs or blockages occurred for all three wet-mix shotcrete mixtures. All three wet-mix shotcrete mixtures shot well and were able to build up vertical thickness of up to 150 mm (6") but with different adhesion perormance. (Fig. B-5 to B-10, B-12 to B-14). The plain wet-mix shotcrete sloughed off the plywood form after 150 mm thickness was reached. The wet-mix shotcrete with microsynthetic fiber remained adhered when 150 mm thickness was reached, but sloughed when an attempt was made to cut it with a steel trowel (Fig. B-13). By contrast, the NForce-Fiber reinforced wet-mix shotcrete demonstrated great adhesion (sticking to the plywood form) and cohesion (sticking to itself) during shooting. The NForce-Fiber wet-mix shotcrete could be cut and carved with a steel trowel without inducing any sloughing as is well illustrated in Figs. B-8 to B-10. This is a highly desirable attribute of shotcrete.

Vertical rebound was tested inside the rebound chamber (Fig. B-12 & B-14). Table 3 lists test results. These are typical for a fly ash modified wet-mix shotcrete as used in industry. The NForce-Fiber reinforced wet-mix shotcrete has the lowest vertical rebound, and the microsynthetic fiber reinforced wet-mix shotcrete has the highest vertical rebound. This reduced rebound in the NForce-Fiber reinforced shotcrete is consistent with its observed improved adhesion and cohesion relative to the plain shotcrete mixture and mixture with microsynthetic fiber.

Table 3. Rebound Test Results for Wet-Mix Shotcrete Mixtures

Mixture	Fiber Content		Vertical Rebound
	(kg/m^3)	(% volume)	
WP	0	0	11.5%
WNF (2.0)	2	0.15	10.9%
WSF	1.35	0.15	14.6%

3.4 Plastic Shrinkage Cracking Testing

Plastic shrinkage cracking testing was conducted to *ASTM C1579 Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert)* [Ref. 3]. Two panels were shot, finished and tested for each wet-mix shotcrete mixture. After finishing, the samples were placed in environmental chambers which provided an environment of: temperature 36 +/- 3 ^{0}C; wind velocity 4.7 m/s; and relative humidity 30 +/-10%, as required by the test method.

In addition, a water sample in a beaker was placed in each of the environmental chambers to monitor the evaporation rate. ASTM C1579 specifies a minimum rate of evaporation of 1.0 kg/m^2.h and this requirement was met. A setting time test was conducted to determine the set time to ASTM C403. Once the shotcrete samples reached final set, samples were removed from the environmental chambers and placed in the laboratory for curing at 23+/-2 ^{0}C and 50% relative humidity, until 24 hours, as prescribed in the test method. Cracks were measured to determine shrinkage performance using the methodology provided in ASTM C1579. Test results and photos are included in Appendix D and summarized in Table 4 as follows:

Table 4. Plastic Shrinkage Test Results for Wet-Mix Shotcrete Mixtures

Mixture	Fiber Content		Crack Reduction Ratio (CRR), %
	(kg/m^3)	(% volume)	
WP	0	0	N/A
WNF	2	0.15	92
WSF	1.35	0.15	84

Table 4 shows that when NForce-Fiber was added at 2.0 kg/m^3, i.e., 0.15% by volume, the crack reduction ratio, as defined by ASTM C1579, is 92%. When microsynthetic fiber was added at 1.35 kg/m3, i.e., 0.15% by volume, the crack reduction ratio is 84%. This shows that when NForce-Fiber was added at the same % by volume as the microsynthetic fiber, it is more efficient in mitigating plastic shrinkage cracking.

3.5 Finishability

After samples were shot, no evidence of sedimentation, segregation or bleeding was observed in any of the mixes. Wet-mix shotcrete mixtures were shot into 355x550x100 mm plywood boxes and finished using different hand-held finishing tools to evaluate the finishability of the different mixes. The finishing tools used (in sequence from smoothest to most textured finish) are shown in Fig. E-1 in Appendix E and were: steel trowel, magnesium trowel, wood float, hard rubber float, textured rubber float, and sponge float. Photographs of the finished surface texture with each of these finishing tools, for the different mixes, are provided in Appendix E.

The plain shotcrete mix was relatively easy to finish with all of the selected finishing tools, showing the expected sequence of smoothest to greatest surface texture for the different tools, as described above. The mix with microsynthetic fiber (Mix WSF), proved to be the most difficult to finish, with the finishing tools which provided greater surface texture (e.g. rubber float finish and sponge float finish) pulling more fibers to the surface and creating a quite rough finished surface texture with lots of protruding fibers, as is evident in photos E8 to E13 in Appendix E.

By contrast, the mix with NForce-Fiber (WNF) displayed superior finishing characteristics to both the plain shotcrete (WP) and microsynthetic fiber shotcrete (WSF) mixes. The NForce-Fiber appeared to act as a “finishing aid”, providing the mixes with greater cohesiveness, which resulted in relatively smoother textured surface finishes for all of the finishing tools used, particularly when compared to the WSF mix. Virtually no fibers were evident in the finished surface of WNF mixes finished with steel and magnesium trowels. Very few fibers were drawn to the finished surface with the wood, rubber or sponge floats. This is well illustrated in the photos in Appendix E.

4 HARDENED CONCRETE TESTS

4.1 Compressive Strength

For each mix, three cores (75 mm diameter) were extracted and tested for compressive strength at 7 and 28 days to ASTM C39. The compressive strength results are included in Appendix F and are summarized in Table 5 as follows:

Table 5. Compressive Strength for Wet-Mix Shotcrete Mixtures

Mixture	Fiber Content		7 Days Compressive Strength (MPa)	28 Days Compressive Strength (MPa)
	(kg/m^3)	(% volume)		
WP	0	0	35.0	47.9
WNF	2	0.15	43.7	57.6
WSF	1.35	0.15	36.6	51.7

The minimum concrete compressive strength, as required by CSA A23.1/23.2 for a C1 Exposure class, is 35 MPa at 28 days. All mixes readily meet the specified strength requirement of 35 MPa at 28 days. The mix with NForce-Fiber, has the highest compressive strength of all the mixtures at both 7 & 28 days.

4.2 Boiled Absorption and Volume of Permeable Voids

For each mix, three samples were prepared and tested at 28 days for Boiled Absorption (BA) and Volume of Permeable Voids (VPV) to ASTM C642. Test results are included in Appendix G and are summarized in Table 6 as follows:

Table 6. Boiled Absorption and Volume of Permeable Voids

Mixture	Fiber Content		Boiled Absorption (%)	Volume of Permeable Voids (%)
	(kg/m^3)	(% volume)		
WP	0	0	5.3	11.9
WNF	2	0.15	5.1	11.5
WSF	1.35	0.15	5.4	12.0

Results for boiled absorption and volume of permeable voids, as listed in Table 6, show that all three mixes have BA and VPV values well below the maximum BA of 8% and maximum VPV of 17% recommended in ACI 506 Guide to Shotcrete [Ref. 5]. Mixes with microsyntehtic fiber and NForce-Fiber have amost the same BA and VPV value as the plain shotcrete mix without fibers. This shows that the permeability of shotcrete will not be adversely affected by addition of these fibers. Rather, the addition of NForce-Fiber slightly reduced permeability of the wet-mix shotcrete.

4.3 Rapid Chloride Penetration Test (RCP)

For each mix, three samples were prepared for testing at 91 days to ASTM C1202 for Rapid Chloride Penetrability (RCP). Test results are provided in Appendix H and are summarized in Table 7 as follows:

Table 7. Rapid Chloride Penetration Resistance

Mixture	Fiber Content		RCP Results at 91 Days (Coulombs)
	(kg/m^3)	(% volume)	
WP	0	0	966
WNF	2.0	0.10	1037
WSF	1.35	0.15	898

These test results show that all the wet-mix shotcrete mixtures have RCP results at 91 days of between 898 and 1037 Coulombs, which is considered as “low” by both ASTM C1202 and CSA A23.1/23.2-2014. These results also satisfy the CSA A23.1/23.2-2014 requirements for a Class C1 Exposure of not more than 1500 Coulombs at 91 days. This shows that addition of the NForce-Fibers and microsynthetic fibers does not aversely affect the RCP test results.

4.4 Residual Flexural Strength to ASTM C1399 and Flexural Strength and Flexural Toughness to ASTM C1609

For each mix, three beams, with dimensions of 100 x100 x350 mm, were cut from the test panels and cured and tested at 28 days for flexural strength and flexural toughness to ASTM C1609.

Also for each mix, three beams, with dimensions of 100 x100 x350 mm, were prepared and tested at 28 days for residual flexural strength to ASTM C1399. Detailed test results are included in Appendix I and are summarized in Table 8 as follows.

Table 8 shows that addition of both NForce-Fiber and microsyntehtic fibers slightly decreases the flexural strength, when tested to ASTM C1609. The flexural toughness test panels for plain wet-mix shotcrete, NForce-Fiber reinforced shotcrete and microsynthetic fiber reinforced shotcrete in the ASTM C1609 test are all zero. This is due to the fact that the beams completely fractured into two parts at the peak load. The residual flexural strength, when tested to ASTM C1399 for NForce-Fiber, is 0.05 MPa. The residual flexural strength for the microsynthetic fiber reinforced shotcrete is 0.34 MPa.

Table 8. Flexural Strength, Flexural Toughness and Residual Flexural Strength

Mixture	Fiber Content		Flexural Strength to ASTM C1609 (MPa)	Flexural Toughness to ASTM C1609, $T_{100, 2.0}$ (Joules)	Residual Flexural Strength to ASTM C1399 (MPa)
	(kg/m^3)	(% volume)			
WP	0	0	7.27	0.0	0.0
WNF	2.0	0.15	5.33	0.0	0.05
WSF	1.35	0.15	5.62	0.0	0.34

5 DISCUSSION AND CONCLUSIONS

The following conclusions are reached with respect to the performance of NForce Fiber in wet-mix shotcrete compared a plain wet-mix shotcrete without fiber addition and a wet-mix shotcrete with Microsynthetic Fiber addition, in this Phase I "*Product Study and Due Diligence Phase*".

1. All the wet-mix shotcrete mixes, with and without fiber addition, were batched without difficulty and supplied in 0.5 cu.yd. bulk bin bags by Basalite. All the shotcrete mixes were readily mixed in a 1.0 cu.yd. pan mixer with counterrotating paddles to produce uniform mixes without fiber balling or segregation. Such pan mixers are commonly used in the precast concrete industry.

2. The plain wet-mix shotcrete and mixes with NForce-Fiber and Microsynthetic Fiber all had essentially the same as-batched mixture proportions, except that the NForce-Fiber mix had 0.15% fiber volume addition (2 kg/m^3) and the Microsynthetic Fiber mix had 0.15% fiber volume addition (1.35 kg/m^3).

3. The mixes all had slumps in the 50 to 70mm range and as-shot air contents in the 4 to 5% range. The NForce fiber mix required a slightly higher high-range water reducing admixture (superplasticizer) dosage than the other two mixes to produce the required slump without adding any additional water. All three mixes had the same water/cementing materials ratio of 0.40.

4. All three as-shot mixes satisfied the CSA A23.1/23.2-2014 requirements for a Class C1 Exposure. i.e. *Structurally reinforced concrete exposed to chlorides with or without freezing and thawing.*

5. All three shotcrete mixes were readily pumpable and shot well. No problems of fiber balls or line blockages were encountered during shooting. All three mixes were built up to a thickness of 150mm on a vertical plywood surface in a single shotcrete application.

6. There were, however, some distinct differences in the adhesion and cohesion performances of the different mixes. The plain wet-mix shotcrete sloughed off a vertical plywood form after 150mm thickness had been shot. The Microsynthetic Fiber mix remained adhered to the vertical plywood form when 150mm thickness was reached, but sloughed off the form when an attempt was made to cut it with a steel trowel. (See Fig. B-13 in Appendix B). In strong contrast, the NForce-Fiber mix demonstrated great adhesion (sticking to the plywood form) and cohesion (sticking to itself). At the built up thickness of 150mm it could be readily cut and carved without sloughing from the vertical plywood form. (See Figs. B-9 and B-10 in Appendix B). In fact, it required considerable effort with a flat spade to remove the shot material from the form (as required for rebound testing calculations).

7. The wet-mix shotcrete with NForce-Fiber displayed the lowest rebound of the three mixes shot onto a vertical plywood surface.

8. In Plastic Shrinkage Cracking testing to ASTM C1579 the NForce-Fiber mix produced a Crack Reduction Ratio (CRR) of 92% relative to the plain control wet-mix shotcrete. The Microsynthetic Fiber mix produced a CRR of 84%. i.e, when added at equivalent fiber addition rates of 0.15% by volume, the NForce-Fiber is more effective in mitigating plastic shrinkage cracking in wet-mix shotcrete than the Microsynthetic fiber evaluated.

9. Finishing tests were conducted on shotcrete test panels using the following finishing tools (sequenced from smoothest to roughest finished texture): steel trowel, magnesium trowel, wood float, hard rubber float, textured rubber float and sponge float). The wet-mix shotcrete with NForce-Fiber was the easiest to finish and resulted in the least rough and most uniform finish texture appearance for all of the mixes. The fibers appeared to act as a *finishing aid.* Virtually no fibers were visible in the shotcrete panels finished with steel and magnesium trowels and very few fibers were drawn to the surface by the wood, rubber or sponge floats. This is in marked contrast to the panels shot with Microsynthetic Fibers, were some fibers were visible in the surface of the steel and magnesium troweled panels and progressively more fibers (with rougher textured finishes) were present in panels finished with wood, rubber and sponge floats.

10. All the wet-mix shotcrete mixes readily met the CSA A23.1/23.2-2014 minimum compressive strength requirement of 35MPa at 28 days for a Class C1 Exposure. The mix with NForce-Fiber, however, had significantly higher compressive strengths at 7 and 28 days than the plain mix, or the mix with Microsynthetic Fiber.

11. In the ASTM C642 test, all the wet-mix shotcrete mixes readily met the ACI 506R Guide to Shotcrete recommendations of maximum values of Boiled Absorption (BA) of 8% and Volume of Permeable Voids (VPV) of 17%. Lowest values were found in the wet-mix shotcrete mix with NForce-Fiber, showing that the addition of this fiber has no detrimental effect on shotcrete permeability.

12. In the ASTM C1202 Rapid Chloride Penetrability test the test results at 91 days for the three wet-mix shotcrete mixes ranged from 898 to 1037 Coulombs. These results would be classified as "*Low*" by both ASTM C1202 and CSA A23.1/23.2-2014 and readily meet

the CSA A23.1/23.2-2014 requirements for a Class C1 Exposure of not more than 1500 Coulombs at 91 days.

13. The addition of NForce-Fiber or Microsynthetic Fiber resulted in a small reduction in the 28 day flexural strength and provided no Toughness when tested in the ASTM C1609 flexural beam test. Residual Flexural strength test results were low in the ASTM C1399 test for both the NForce-Fiber and Microsynthetic wet-mix shotcretes with 0.15% fiber volume addition.

In summary, the addition of NForce Fiber to a wet-mix shotcrete has a number of beneficial attributes. These include:

a) A remarkable enhancement of the adhesion and cohesion of the freshly applied shotcrete mix, with resulting reduction in rebound and improved cutting, carving and finishing characteristics.
b) Acted as a "*finishing aid",* leaving a smoother textured surface, with very few fibers present in the finished surface, compared to the mix with Microsynthetic fiber.
c) Very effective in reducing plastic shrinkage cracking; more so than Microsynthetic fiber.
d) Some enhancement of the properties of the hardened shotcrete such as compressive strength and permeability.

6 RECOMMENDATIONS

It is recommended that the performance of wet-mix shotcrete incorporating 0.15% volume (2 kg/m^3) of NForce-Fiber be evaluated in a full-scale field application, using ready mix concrete batching, mixing and supply and conventional wet mix-shotcrete pumping and shooting. It is recommended that the shotcrete be used in an application such as a structural shotcrete wall, or other project with shotcrete finishing requirements, (e.g canal lining or remedial works) so that the expected enhancements in finishing characteristics can be evaluated in the field.

The field performance of the wet-mix shotcrete with NForce-Fiber should be evaluated for plastic properties such as: slump, air content, shooting and finishing characteristics. The hardened shotcrete should be evaluated for properties such as resistance to cracking and compressive strength at 7 and 28 days. Cores should also be extracted from test panels for determination of ASTM C642 values of Boiled Absorption (BA) and Volume of Permeable Voids (VPV) at 28 days. Cores could also be extracted from test panels for determination of Coulomb values at 91 days in the ASTM C1202 Rapid Chloride Penetrability test.

LZhang Consulting and Testing Ltd would be pleased, on request, to provide the recommended wet-mix shotcrete quality control tests for such a field application and provide a report with findings.

Respectfully submitted,

by LZhang Consulting & Testing Ltd

Reviewed by

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3. ASTM C1579-2009 Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert).
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Appendix A: WET-MIX SHOTCRETE MIX DESIGN Mix WP (Plain Wet-Mix Shotcrete)

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LZhang File No: 11VA062
Date: 04-Dec-15

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation

SUBJECT: Mix WP (Plain Wet-Mix Shotcrete) Mix Design

Material		Mass per m^3 SSD Agg [kg]	Density [kg/m^3]	Volume [m^3]
Cement Type GU (ASTM Type I)		360	3150	0.1143
Flyash		90	2550	0.0353
Coarse Aggregate (10-5 mm, SSD)		430	2730	0.1575
Fine Aggregate (SSD)		1290	2673	0.4826
Water, L		180	1000	0.1800
Water Reducing Admixture, L *		1.150	1010	0.0011
Air-Entraining Admixture (BASF MBAE 90), L		0.110	1010	0.0000
Air Content:	At pump +/- 1.5%	7-10%	-	-
Air Content:	As shot +/- 1.5%	4.5	-	0.0450
Total		2351	Yield (m^3)=	1.0166

NOTES

*Glenium added during mixing at dosage required to achieve the maximum allowable W/CM ratio and required slump
** Specific Gravity of NForce fiber is provided by Canadian Greenfield Technologies Corp.
*** Air entraining admixture added during mixing at dosage required to produce required air content

PROJECT REQUIREMENTS

Minimum Compressive Strength	30 MPa at 7 days, 40 MPa at 28 days
Slump	70+/-20 mm
Maximum W/CM Ratio	0.40
Air Content as shot	3.0-6.0 % by volume
Rapid Chloride Permeability (ASTM C1202)	<1500 Coulombs at 91 days
Maximum Boiled Absorption (ASTM C642)	8%
Maximum Volume of Permeable Voids (ASTM C642)	17%

CALCULATED MIX DESIGN PARAMETERS

Fine Aggregate Content	75%
Plastic Density (kg/m^3)	2313
Fly Ash Content (% by mass of cement+fly ash)	20.0%
W/CM Ratio	0.40

Per: Lihe (John) Zhang, Ph.D., P.Eng
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Appendix A: WET-MIX SHOTCRETE MIX DESIGN Mix WNF (NForce-Fiber Wet-Mix Shotcrete)

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LZhang File No: 11VA062
Date: 04-Dec-15

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation

SUBJECT: Mix WNF (NForce-Fiber Wet-Mix Shotcrete) Mix Design

Material		Mass per m^3 SSD Agg [kg]	Density [kg/m^3]	Volume [m^3]
Cement Type GU (ASTM Type I)		360	3150	0.1143
Flyash		90	2550	0.0353
Coarse Aggregate (10-5 mm, SSD)		430	2730	0.1575
Fine Aggregate (SSD)		1290	2673	0.4826
Water, L		180	1000	0.1800
Water Reducing Admixture, L *		1.300	1010	0.0013
NForce Fiber**		2.000	1480	0.0014
Air-Entraining Admixture (BASF MBAE 90), L		0.130	1010	0.0000
Air Content:	At pump +/- 1.5%	7-10%	-	-
Air Content:	As shot +/- 1.5%	4.5	-	0.0450
Total		2353	Yield (m^3)=	1.0181

NOTES

*Glenium added during mixing at dosage required to achieve the maximum allowable W/CM ratio and required slump
** Specific Gravity of NForce fiber is provided by Canadian Greenfield Technologies Corp.
*** Air entraining admixture added during mixing at dosage required to produce required air content

PROJECT REQUIREMENTS

Minimum Compressive Strength	30 MPa at 7 days, 40 MPa at 28 days
Slump	70+/-20 mm
Maximum W/CM Ratio	0.40
Air Content as shot	3.0-6.0 % by volume
Rapid Chloride Permeability (ASTM C1202)	<1500 Coulombs at 91 days
Maximum Boiled Absorption (ASTM C642)	8%
Maximum Volume of Permeable Voids (ASTM C642)	17%

CALCULATED MIX DESIGN PARAMETERS

Fine Aggregate Content	75%
Plastic Density (kg/m^3)	2311
Fly Ash Content (% by mass of cement+fly ash)	20.0%
W/CM Ratio	0.40

Per: Lihe (John) Zhang, Ph.D., P.Eng
Materials Engineer
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Appendix A: WET-MIX SHOTCRETE MIX DESIGN Mix WSF (Microsynthetic Fiber Wet-Mix Shotcrete)

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LZhang File No: 11VA062
Date: 04-Dec-15

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation

SUBJECT: Mix WSF (Microsynthetic Fiber Wet-Mix Shotcrete) Mix Design

Material		Mass per m^3 SSD Agg [kg]	Density [kg/m^3]	Volume [m^3]
Cement Type GU (ASTM Type I)		360	3150	0.1143
Flyash		90	2550	0.0353
Coarse Aggregate (10-5 mm, SSD)		430	2730	0.1575
Fine Aggregate (SSD)		1290	2673	0.4826
Water, L		180	1000	0.1800
Water Reducing Admixture, L *		1.050	1010	0.0010
Interstar Microsynthetic Fiber		1.350	920	0.0015
Air-Entraining Admixture (BASF MBAE 90), L		0.125	1010	0.0000
Air Content:	At pump +/- 1.5%	7-10%	-	-
Air Content:	As shot +/- 1.5%	4.5	-	0.0450
Total		2353	Yield (m^3)=	1.0180

NOTES

*Glenium added during mixing at dosage required to achieve the maximum allowable W/CM ratio and required slump
** Air entraining admixture added during mixing at dosage required to produce required air content

PROJECT REQUIREMENTS

Minimum Compressive Strength	30 MPa at 7 days, 40 MPa at 28 days
Slump	70+/-20 mm
Maximum W/CM Ratio	0.40
Air Content as shot	3.0-6.0 % by volume
Rapid Chloride Permeability (ASTM C1202)	<1500 Coulombs at 91 days
Maximum Boiled Absorption (ASTM C642)	8%
Maximum Volume of Permeable Voids (ASTM C642)	17%

CALCULATED MIX DESIGN PARAMETERS

Fine Aggregate Content	75%
Plastic Density (kg/m^3)	2311
Fly Ash Content (% by mass of cement+fly ash)	20.0%
W/CM Ratio	0.40

Per: Lihe (John) Zhang, Ph.D., P.Eng
Materials Engineer
LZhang Consulting & Testing Ltd

Reviewed by: D.R. Morgan, Ph.D., P.Eng
Principal Consultant

APPENDIX B Field wet-mix trial shoot with NForce-Fiber

Figure B-1: Pre-bagged materials (0.5 yd^3) discharged into the panel mixer, water and water reducing admixture manually added to adjust slump. Putzmeister wet-mix shotcrete pump used to pump the shotcrete.

Figure B-2: Wet-mix shotcrete inside the pan mixer

Figure B-3: Shooting panel for plastic shrinkage testing

Figure B-4. Shooting test panels

Figure B-5: Vertical rebound test for plain wet-mix shotcrete

Figure B-6: Plain wet-mix shotcrete vertical thickness build-up

Figure B-7: NForce-Fiber wet-mix shotcrete vertical thickness build-up & measurement

Figure B-8: Testing the cohesiveness of the NForce-Fiber wet-mix shotcrete

Figure B-9: Testing the cohesiveness of the NForce-Fiber wet-mix shotcrete

Figure B-10: Testing the cohesiveness and adjesion of the NForce-Fiber wet-mix shotcrete. Note that the shotcrete adhered to the wall and no sloughing occured after multiple cuts with a steel trowel

Figure B-11: Slump test for microsynthetic fiber wet-mix shotcrete

Figure B-12: Vertical rebound test and thickness build up for microsynthetic fiber wet-mix shotcrete

Figure B-13: Vertical thickness build up for microsynthetic fiber wet-mix shotcrete. Note that shotrete sloughed after cut by a steel trowl

Figure B-14: Vertical rebound test: note the rebound materials on the floor were collected and weighed and materials adhered to the vertical wall were also collected and weighed.

Figure B-15 Test panels were saw-cut to beams

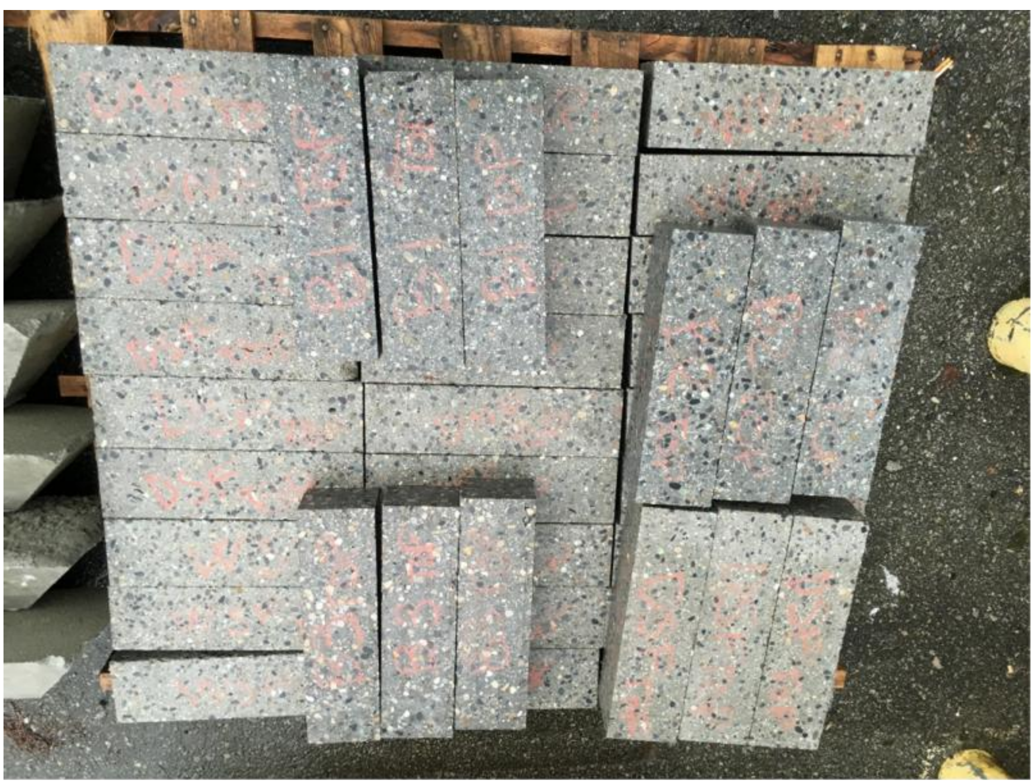

Figure B-16 Beams were cut to 100 +/- 2 mm for ASTM C1609 & ASTM C1399 tests

Appendix C: Plastic Properties

CANADIAN GREENFIELD TECHNOLOGIES CORP.
Mr. Mike Pildysh, M.Eng., P.Eng, President
#159, 3953 112 Ave SE
Calgary, AB
Canada, T2C 0J4

LZhang File No: 11VA062
Date: 29-Feb-16

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation

SUBJECT: Shotcrete Plastic Properties

Date Shot: 27-Feb-16 **Wet-Mix Fiber Reinforced Shotcrete** **Ambient Temperature:** 7 ^oC

Mixture	Fiber Content		Slump (mm)	As-Batched Air Content (%)	As-Shot Air Content (%)	Shotcrete Temperature (^oC)	Superplasticizer, Glenium 7500, (ml/m^3)	Air Entraining Agent (ml/m^3)	Evaporation Rate ($kg/m^2.h$) in ASTM C1579 Test
	(kg/m^3)	(% volume)							
WP	0	0	50	5.5	-	13.0	1150	110	1.25
WNF	2	0.15	70	9.0	4.3	18.0	1300	130	1.25
WSF	1.35	0.15	60	8.0	4.8	20.0	1050	130	1.25

Per: Lihe (John) Zhang, Ph.D., P.Eng
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Appendix D: Plastic Shrinkage Test

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Calgary, AB
Canada, T2C 0J4

LZhang File No: 11VA062
Date: 29-Feb-16

PROJECT: NForce-Fiber Reinforced Shotrete Evaluation

SUBJECT: Plastic Shrinkage Test to ASTM C1579

Mixture	Shot Date	Fiber Content (kg/m^3)	Fiber Content (% volume)	Panel #	Crack Width (mm)	Crack Reduction Ratio (CRR), %
WP	**27-Feb-16**	Plain Wet-Mix Shotcrete	0.00	Panel #1	0.5	**N/A**
				Panel #2	0.75	
				Average	0.63	
WNF		NForce-Fiber, 2.0	0.15	Panel #1	0.1	**92**
				Panel #2	0.0	
				Average	0.05	
WSF		Microsynthetic fiber, 1.35	0.15	Panel #1	0.0	**84**
				Panel #2	0.2	
				Average	0.10	

Per: Lihe (John) Zhang, Ph.D., P.Eng
LZhang Consulting & Testing Ltd
5069 7B Avenue
Delta, BC, V4M 1S3

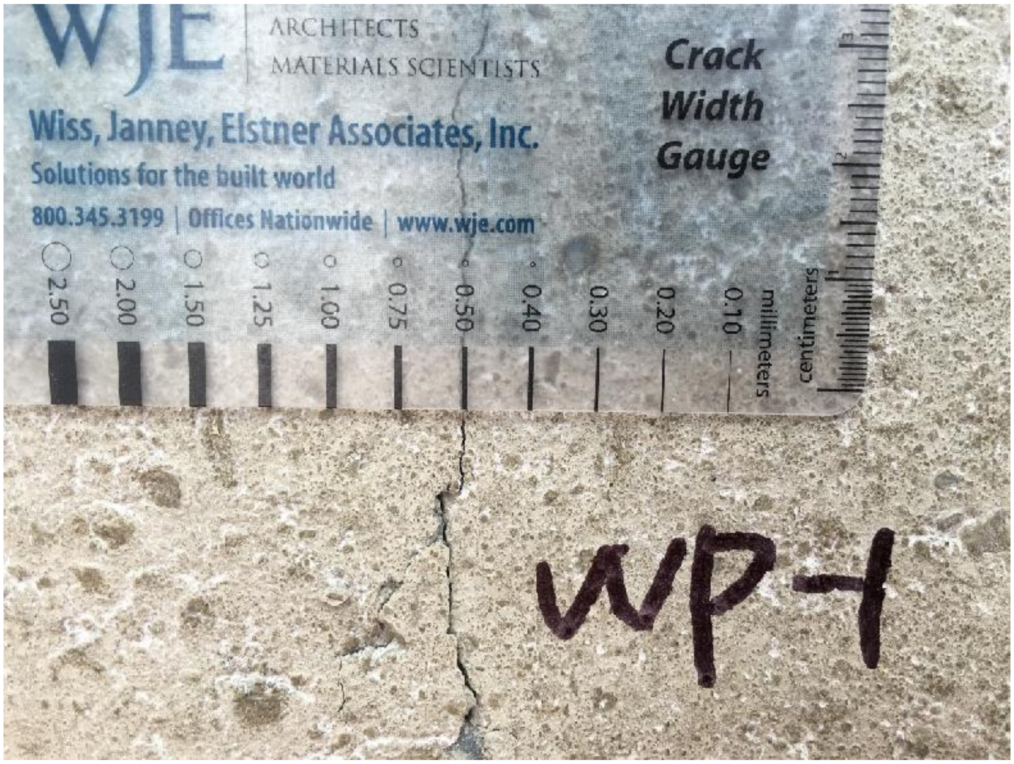

Figure D-1: Plain wet-mix shotcrete panel #1, 0 kg/m³ fiber, crack width of 0.5 mm

Figure D-2: Plain wet-mix shotcrete panel #2, 0 kg/m³ fiber, crack width of 0.75 mm

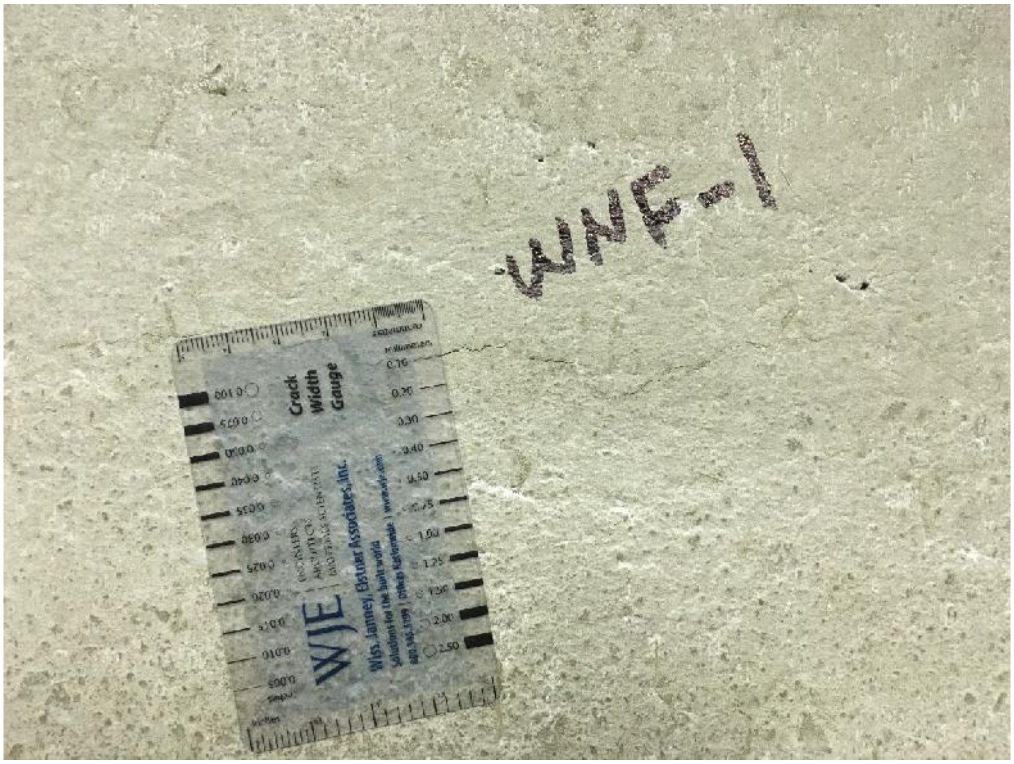

Figure D-3: NForce-Fiber panel #1, 2 kg/m^3 fiber, 0.10 mm crack width

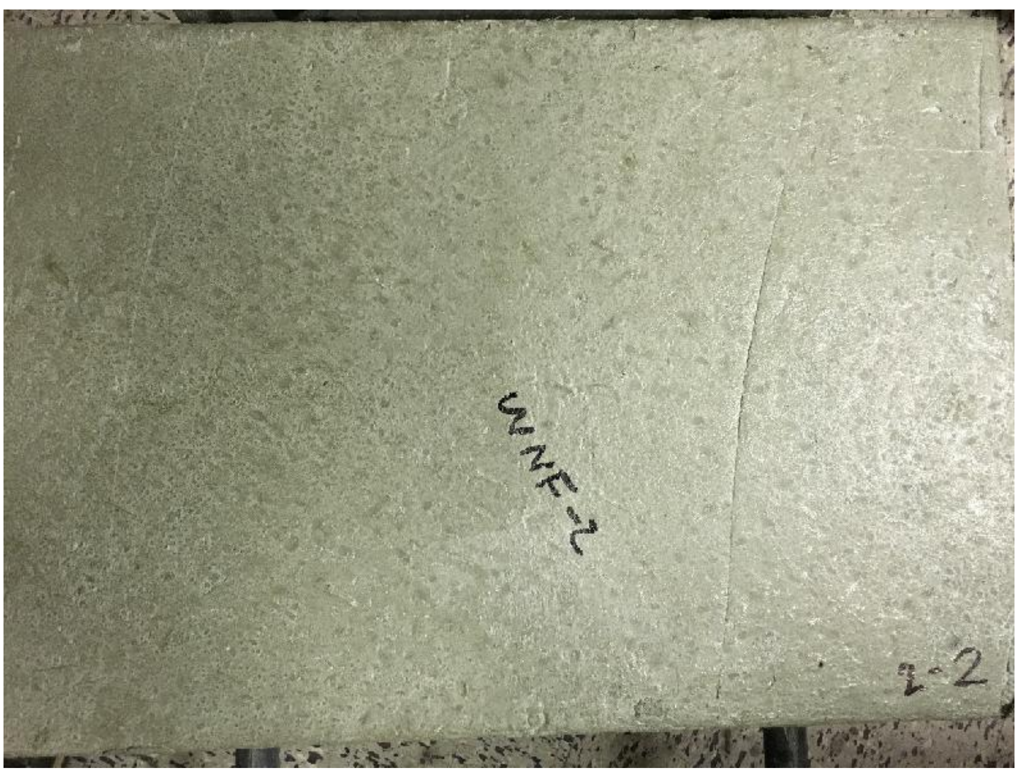

Figure D-4: NForce-Fiber panel #2, 2 kg/m^3 fiber, 0mm crack width

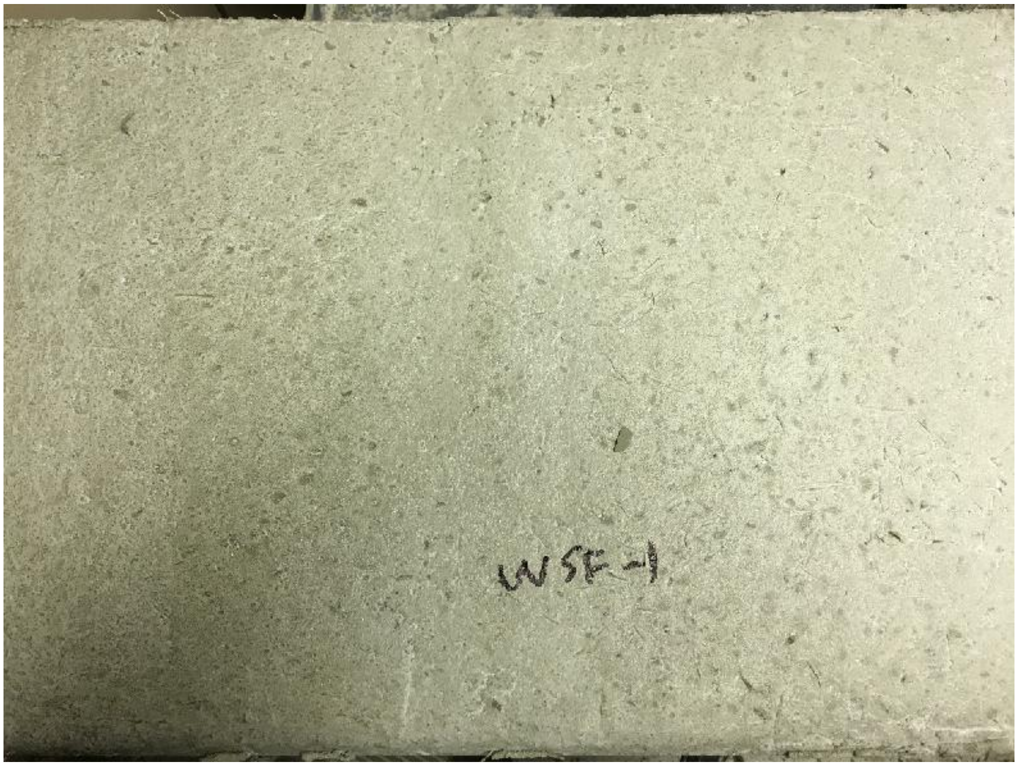

Figure D-5: Microsynthetic fiber panel #1, 1.35 kg/m^3 fiber, crack width of 0 mm

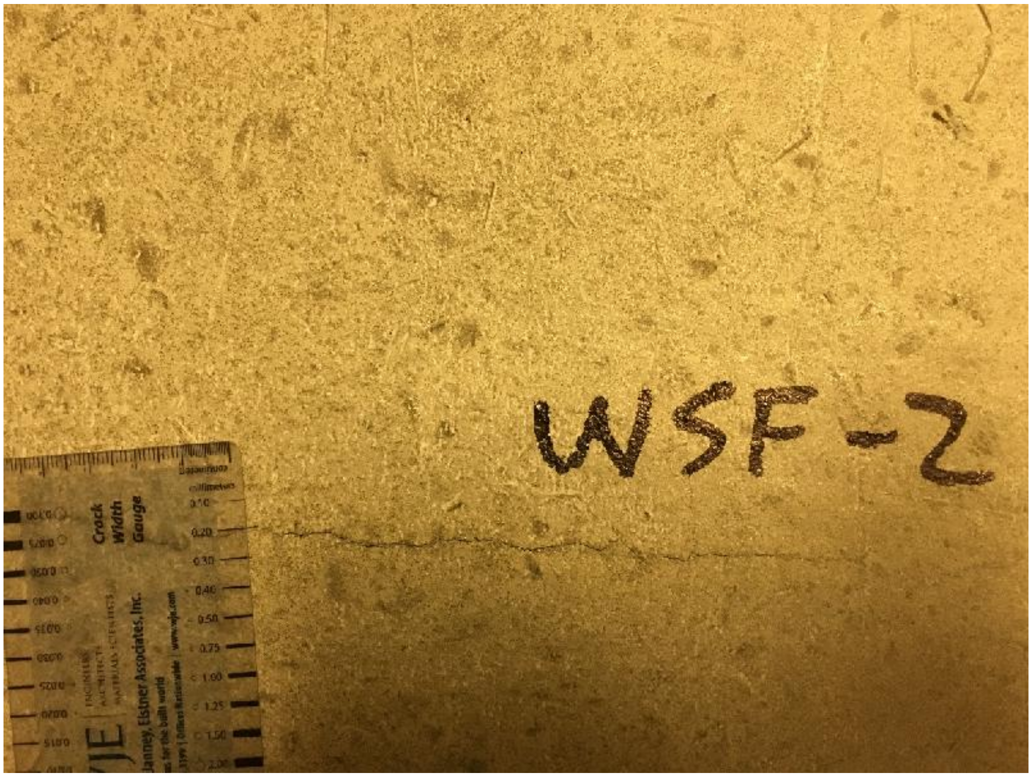

Figure D-6: Microsynthetic fiber panel #2, 1.35 kg/m^3 fiber, crack width of 0.2 mm

APPENDIX E Finishability Evaluation

Figure E-1: Finishing tools (left to right): steel trowel, magnesium trowel, wood float, hard rubber float, textured rubber float, sponge float

Figure E-2: Plain wet-mix shotcrete mix finish: steel trowel finish

Figure E-3: Plain wet-mix shotcrete mix finish: magnesium finish

Figure E-4: Plain wet-mix shotcrete mix finish: wood float finish

Figure E-5: Plain wet-mix shotcrete mix finish: hard rubber float finish

Figure E-6: Plain wet-mix shotcrete mix finish: textured rubber float finish

Figure E-7: Plain wet-mix shotcrete mix finish: sponge float finish

Figure E-8: Microsynthetic fiber wet-mix shotcrete finish: steel trowel finish

Figure E-9: Microsynthetic fiber wet-mix shotcrete finish: magnesium finish

Figure E-10: Microsynthetic fiber wet-mix shotcrete finish: wood float finish

Figure E-11: Microsynthetic fiber wet-mix shotcrete finish: hard rubber float finish

Figure E-12: Microsynthetic fiber mix finish: textured rubber float finish

Figure E-13: Microsynthetic fiber mix finish: sponge float finish

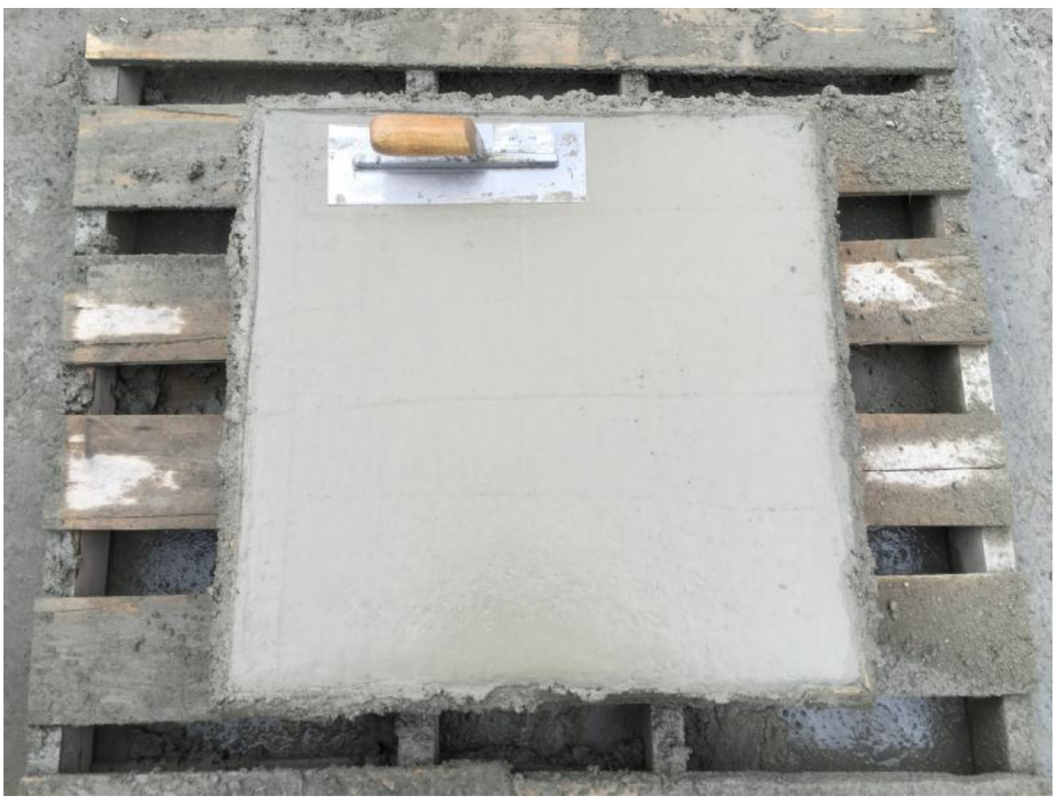

Figure E-14: NForce-Fiber wet-mix shotcrete finish: steel trowel finish

Figure E-15: NForce-Fiber wet-mix shotcrete finish: magnesium finish

Figure E-16: NForce-Fiber wet-mix shotcrete finish: wood float finish

Figure E-17: NForce-Fiber wet-mix shotcrete finish: hard rubber float finish

Figure E-18: NForce-Fiber wet-mix shotcrete finish: textured rubber float finish

Figure E-19: NForce-Fiber finish: sponge float finish

Appendix F: Compressive Strength for Wet-Mix Shotcrete

CANADIAN GREENFIELD TECHNOLOGIES CORP.
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LZhang File No: 11VA062
Date: 27-Mar-16

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation
SUBJECT: Compressive Strength for Wet-Mix Shotcrete Cores to ASTM C1604

Date Shot: 27-Feb-16

Mixture	Fiber Content		Age (days)	Load (kN)	Diameter (mm)	Compressive Strength (MPa)	Length (mm)	Length / Diameter	Corrected Compressive Strength (MPa)	Average Corrected Compressive Strength (MPa)
	(kg/m^3)	(% volume)								
WP	**0**	**0**	7	164.1	74.9	37.3	110.5	1.48	35.4	**35.0**
				156.5	74.5	35.9	102.2	1.37	33.7	
				166.5	74.7	38.0	105.3	1.41	35.8	
			28	220.1	74.4	50.7	103.1	1.39	47.6	**47.9**
				222.7	74.4	51.3	108.1	1.45	48.7	
				216.7	74.4	49.8	107.1	1.44	47.3	
WNF	**2.0**	**0.15**	7	201.3	74.6	46.1	109.4	1.47	43.8	**43.7**
				202.5	74.4	46.6	108.7	1.46	44.3	
				197.1	74.5	45.2	109.1	1.46	42.9	
			28	264.4	74.3	61.0	107.9	1.45	57.9	**57.6**
				268.7	74.3	61.9	109.2	1.47	58.8	
				256.3	74.4	59.0	107.9	1.45	56.1	
WSF	**1.35**	**0.15**	7	166.3	74.5	38.1	108.8	1.46	36.2	**36.6**
				170.9	74.7	39.0	108.8	1.46	37.1	
				166.2	74.4	38.3	109.5	1.47	36.4	
			28	239.0	74.3	55.1	108.5	1.46	52.4	**51.7**
				233.1	74.5	53.4	107.1	1.44	50.7	
				237.5	74.4	54.7	109.2	1.47	52.0	

Per: Lihe (John) Zhang, Ph.D., P.Eng
LZhang Consulting & Testing Ltd
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Appendix G: Boiled Absorption and Volume of Permeable Voids

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Canada, T2C 0J4

LZhang File No: 11VA062
Date: 05-Apr-16

LZhang
Consulting & Testing

PROJECT: **NForce-Fiber Reinforced Wet-Mix Shotcrete Evaluation**
SUBJECT: **Boiled Absorption and Volume of Permeable Voids to ASTM C 642 at 28 Days of Age**

Date Shot: 27-Feb-16
Date Test: 26-Mar-16

Specified BV & VPV: 8% Boiled Absorption, 17% Volume of Permeable Voids

Sample No.	Batch Ticket # & Location	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, %
WP	**No Fiber**	4.8	4.9	2.246	2.353	2.357	2.525	11.1
		5.3	5.5	2.220	2.338	2.342	2.527	12.1
		5.3	5.5	2.223	2.341	2.345	2.534	12.3
Average		**5.1**	**5.3**	**2.230**	**2.344**	**2.348**	**2.529**	**11.8**
WNF	**NForce-Fiber, 2.0 kg/m^3**	4.8	5.1	2.251	2.360	2.365	2.540	11.4
		4.8	5.0	2.263	2.371	2.376	2.553	11.4
		4.9	5.2	2.251	2.362	2.368	2.547	11.6
Average		**4.9**	**5.1**	**2.255**	**2.365**	**2.370**	**2.547**	**11.5**
WSF	**Microsynthetic fiber, 1.35 kg/m^3**	5.0	5.3	2.249	2.362	2.368	2.553	11.9
		5.3	5.6	2.234	2.353	2.359	2.553	12.5
		4.9	5.2	2.254	2.364	2.370	2.550	11.6
Average		**5.1**	**5.4**	**2.246**	**2.360**	**2.366**	**2.552**	**12.0**

Tested by: Manuel Garcia
Technician

Reported by: Lihe (John) Zhang, Ph.D., P.Eng
Materials Engineer
LZhang Consulting & Testing Ltd

Appendix H: Rapid Chloride Penetration Test Results

CANADIAN GREENFIELD TECHNOLOGIES CORP.
Mr. Mike Pildysh, M.Eng., P.Eng, President
#159, 3953 112 Ave SE
Calgary, AB
Canada, T2C 0J4

LZhang File No: 11VA062
Date: 07-Jun-16

LZhang Consulting & Testing

PROJECT: NForce-Fiber Reinforced Concrete Evaluation
SUBJECT: Rapid Chlorid Penetration Test to ASTM C1202

Sample ID	Age (days)	Thickness (mm)	Diameter (mm)	Charge Passed after Six Hours (Coulombs)	Average Charge Passed after Six Hours (Coulombs)	ASTM C1202 Rating	
						Charged Passed (Coulombs)	Chloride Ion Penetrability
WP-1	91	52.1	101.6	908		>4,000	High
WP-2	91	51.5	100.5	969	**966**	2,000-4,000	Moderate
WP-3	91	51.6	100.4	1020		1,000-2,000	Low
WNF-1	91	51.1	100.4	973		100-1,000	Very Low
WNF-2	91	51.2	100.4	998	**1037**		
WNF-3	91	51.4	100.5	1139			
WSF-1	91	51.4	100.5	940			
WSF-2	91	50.5	100.5	846	**898**		
WSF-3	91	50.6	101.3	909			

Comments: 1- Samples are Disc with 50 mm thick saw cut from the top of the concrete cylinder.
2- Specimens cured in the lime water curing tank at 23±1 ° C.

Tested by: Manuel Garcia, Technician
Laboratory Technician

Reported by: Lihe (John) Zhang, Ph.D., P.Eng
Materials Engineer
LZhang Consulting & Testing Ltd

Appendix I: Flexural Toughness to ASTM C1609 Mix WP

CANADIAN GREENFIELD TECHNOLOGIES CORP.
Mr. Mike Pildysh, M.Eng., P.Eng, President
#159, 3953 112 Ave SE
Calgary, AB
Canada, T2C 0J4

LZhang File No: 11VA062
Date: 28-Mar-16

PROJECT: NForce-Fiber Reinforced Dry-Mix Shotcrete Evaluation

SUBJECT: Flexural Performance of Plain Wet-Mix Shotcrete to ASTM C 1609/C 1609 M - 12

Sample No.	Peak Load (kN)	Peak Strength (MPa)	Peak-Load Deflection (mm)	Residual Load (kN)		Residual Strength (MPa)		Toughness	Equivalent Flexural Strength
				$P_{100,0.5}$	$P_{100,2.0}$	$f_{100,0.5}$	$f_{100,2.0}$	$T_{100,\ 2.0}$ (J)	$R_{100,\ 2.0}$
WP-1	25.99	7.43	0.042	Not applicable*					
WP-2	25.02	7.15	0.039						
WP-3	25.26	7.22	0.039						
AVG.	**25.42**	**7.27**	**0.040**						

*All three beams fractured into two parts at peak load, no residual load

Per: LZhang Consulting & Testing Ltd
5069 7B Avenue
Delta, BC V4M 1S3

Appendix I: Flexural Toughness to ASTM C1609 Mix WNF (NForce-Fiber)

CANADIAN GREENFIELD TECHNOLOGIES CORP.
Mr. Mike Pildysh, M.Eng., P.Eng, President
#159, 3953 112 Ave SE
Calgary, AB
Canada, T2C 0J4

LZhang File No: 11VA062
Date: 28-Mar-16

PROJECT: NForce-Fiber Reinforced Wet-Mix Shotcrete Evaluation

SUBJECT: Flexural Performance of NForce-Fiber Fiber-Reinforced Wet-Mix Shotcrete to ASTM C 1609/C 1609 M - 12

Sample No.	Peak Load (kN)	Peak Strength (MPa)	Peak-Load Deflection (mm)	Residual Load (kN)		Residual Strength (MPa)		Toughness	Equivalent Flexural Strength
				$P_{100,0.5}$	$P_{100,2.0}$	$f_{100,0.5}$	$f_{100,2.0}$	$T_{100, 2.0}$ (J)	$R_{100, 2.0}$
WNF (2.0)-1	18.37	5.25	0.041	Not applicable*					
WNF (2.0)-2	18.95	5.42	0.042						
WNF (2.0)-3	18.64	5.33	0.044						
AVG.	**18.65**	**5.33**	**0.042**						

*All three beams fractured into two parts at peak load, no residual load

Per: LZhang Consulting & Testing Ltd
5069 7B Avenue
Delta, BC V4M 1S3

Appendix I: Flexural Toughness to ASTM C1609 Mix WSF (Microsynthetic Fiber)

CANADIAN GREENFIELD TECHNOLOGIES CORP.
Mr. Mike Pildysh, M.Eng., P.Eng, President
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Calgary, AB
Canada, T2C 0J4

LZhang File No: 11VA062
Date: 28-Mar-16

PROJECT: **NForce-Fiber Reinforced Wet-Mix Shotcrete Evaluation**

SUBJECT: **Flexural Performance of Microsynthetic Fiber-Reinforced Wet-Mix Shotcrete to ASTM C 1609/C 1609 M - 12**

Sample No.	Peak Load (kN)	Peak Strength (MPa)	Peak-Load Deflection (mm)	Residual Load (kN)		Residual Strength (MPa)		Toughness $T_{100,\,2.0}$ (J)	Equivalent Flexural Strength
				$P_{100,0.5}$	$P_{100,2.0}$	$f_{100,0.5}$	$f_{100,2.0}$		$R_{100,\,2.0}$
WSF (2.0)-1	19.13	5.47	0.040	Not applicable*					
WSF (2.0)-2	18.50	5.28	0.042						
WSF (2.0)-3	21.37	6.11	0.041						
AVG.	**19.67**	**5.62**	**0.041**						

*All three beams fractured into two parts at peak load, no residual load

Per: LZhang Consulting & Testing Ltd
5069 7B Avenue
Delta, BC V4M 1S3

Appendix I: Residual Strength to ASTM C1399 for Plain Wet-Mix Shotcrete Mix

CANADIAN GREENFIELD TECHNOLOGIES CORP.
Mr. Mike Pildysh, M.Eng., P.Eng, President
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Calgary, AB
Canada, T2C 0J4

LZhang File No: 11VA062
Date: 28-Mar-16

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation

SUBJECT: Flexural Performance of Plain Wet-Mix Shotcrete to ASTM C 1399 - 10

	Initial Loading		Reloading										
				Residual Load (kN)					Residual Strength (MPa)				
Sample No.	Peak Load (kN)	Deflection at Peak Load (mm)	Peak Load at Reloading (kN)	$P_{100,0.5}$**	$P_{100,0.75}$	$P_{100,1.0}$	$P_{100,1.25}$	Average Residual Load (kN)	$f_{100,0.5}$***	$f_{100,0.75}$	$f_{100,1.0}$	$f_{100,1.25}$	Average Residual Strength (MPa)
WP-1	24.08	0.038	0.00										
WP-2	26.35	0.054	0.00										
WP-3	21.11	0.034	0.00										
AVG.	**23.85**	**0.042**	**0.00**	No residual load									

* $P_{100,0.5}$ is the residual load at 0.5 mm deflection
** $f_{100,0.5}$ is the residual strength at 0.5 mm deflection

Per: LZhang Consulting & Testing Ltd
5069 7B Avenue
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Appendix I: Residual Strength to ASTM C1399 Wet-Mix Shotcrete Mix WNF (NForce-Fiber)

CANADIAN GREENFIELD TECHNOLOGIES CORP.
Mr. Mike Pildysh, M.Eng., P.Eng, President
#159, 3953 112 Ave SE
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Canada, T2C 0J4

LZhang File No: 11VA062
Date: 28-Mar-16

PROJECT: NForce-Fiber Reinforced Wet-Mix Shotcrete Evaluation

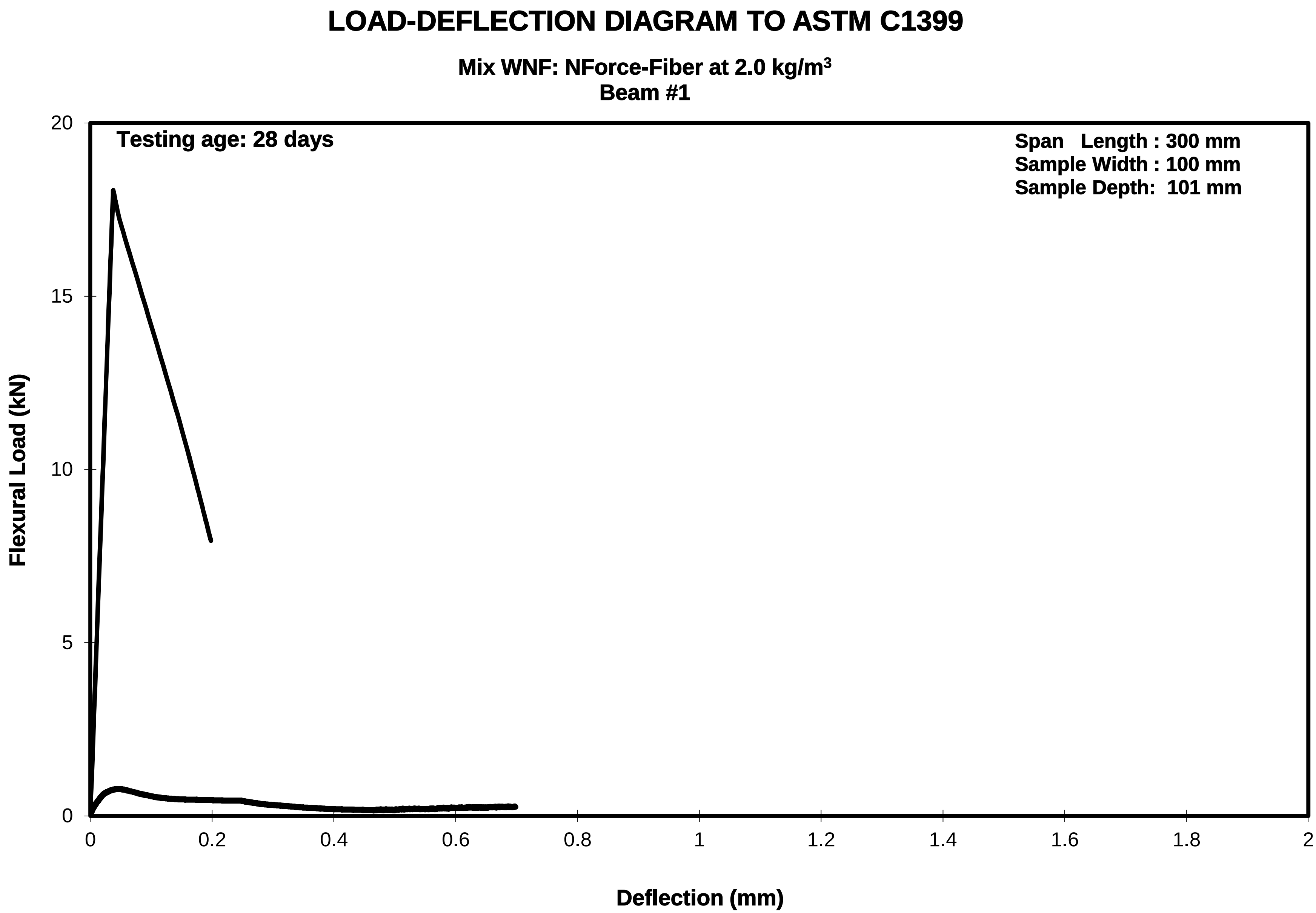
SUBJECT: Flexural Performance of NForce-Fiber Reinforced Wet-Mix Shotcrete to ASTM C 1399 - 10

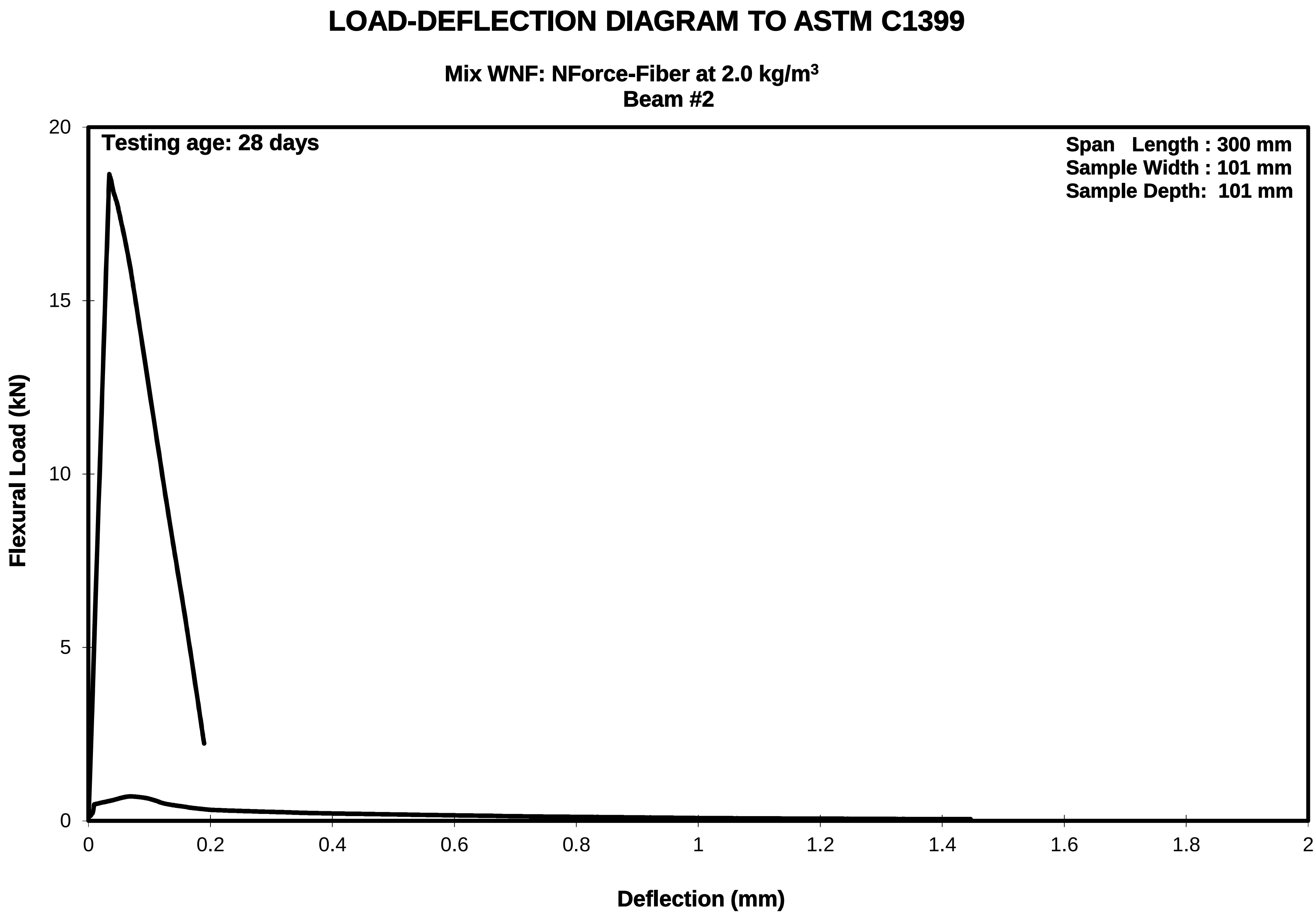
	Initial Loading		Reloading										
				Residual Load (kN)					Residual Strength (MPa)				
Sample No.	Peak Load (kN)	Deflection at Peak Load (mm)	Peak Load at Reloading (kN)	$P_{100,0.5}$**	$P_{100,0.75}$	$P_{100,1.0}$	$P_{100,1.25}$	Average Residual Load (kN)	$f_{100,0.5}$***	$f_{100,0.75}$	$f_{100,1.0}$	$f_{100,1.25}$	Average Residual Strength (MPa)
WNF-1	18.05	0.038	0.78	0.17	0.28	0.17	0.13	0.19	0.05	0.08	0.05	0.04	0.05
WNF-2	18.65	0.034	0.70	0.19	0.12	0.08	0.06	0.11	0.05	0.04	0.02	0.02	0.03
WNF-3	17.47	0.039	0.59	0.28	0.17	0.13	0.10	0.17	0.08	0.05	0.04	0.03	0.05
AVG.	**18.06**	**0.037**	**0.69**	**0.21**	**0.19**	**0.13**	**0.10**	**0.16**	**0.06**	**0.06**	**0.04**	**0.03**	**0.05**

* $P_{100,0.5}$ is the residual load at 0.5 mm deflection

** $f_{100,0.5}$ is the residual strength at 0.5 mm deflection

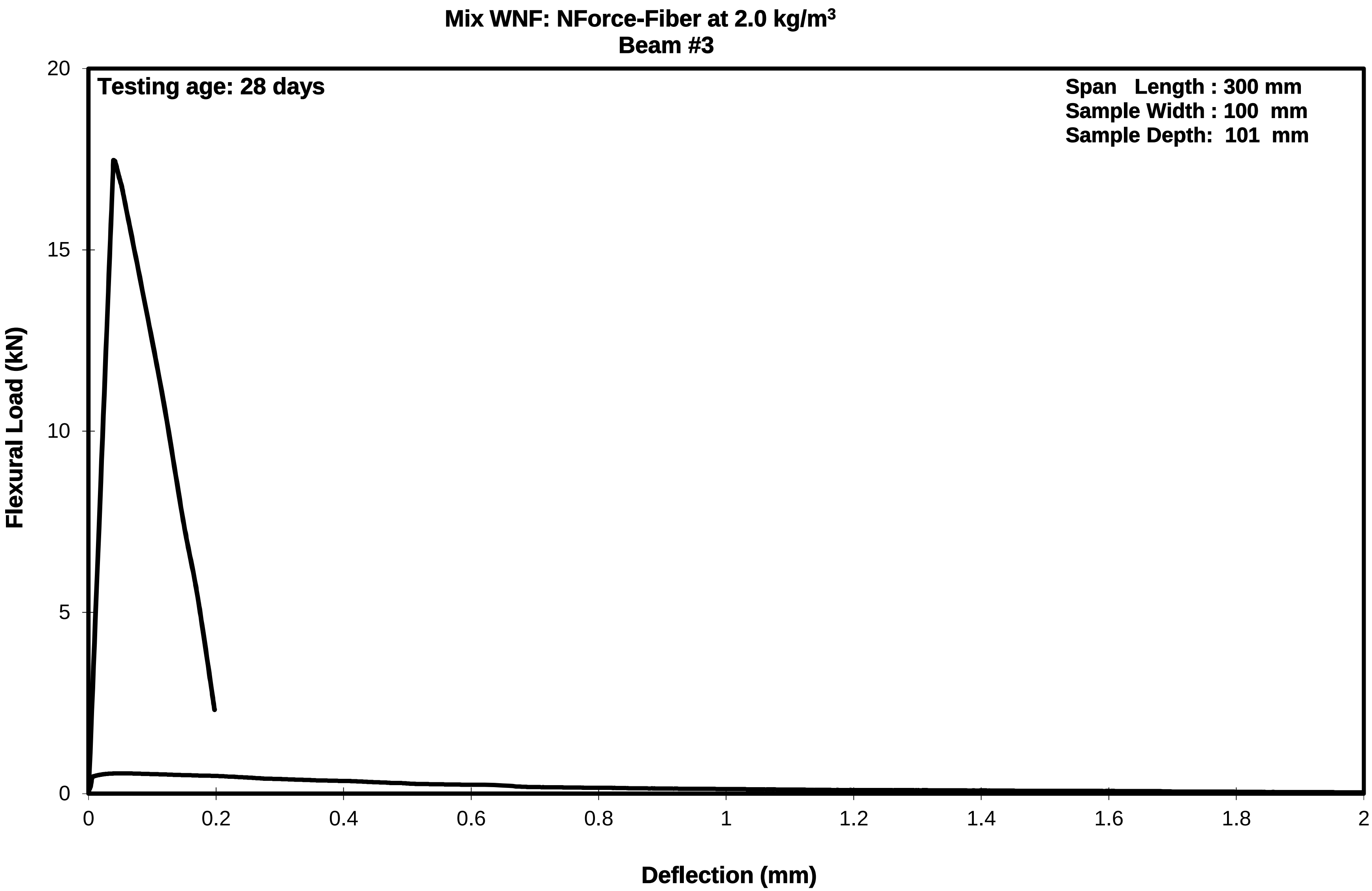
Per: LZhang Consulting & Testing Ltd
5069 7B Avenue
Delta, BC, V4M 1S3


LOAD-DEFLECTION DIAGRAM TO ASTM C1399
Mix WNF: NForce-Fiber at 2.0 kg/m3
Beam #1
Testing age: 28 days
Span Length : 300 mm
Sample Width : 100 mm
Sample Depth: 101 mm
Flexural Load (kN)
Deflection (mm)
0
5
10
15
20
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2



LOAD-DEFLECTION DIAGRAM TO ASTM C1399
Mix WNF: NForce-Fiber at 2.0 kg/m³
Beam #2
Testing age: 28 days
Span Length : 300 mm
Sample Width : 101 mm
Sample Depth: 101 mm
Flexural Load (kN)
Deflection (mm)
0
5
10
15
20
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

LOAD-DEFLECTION DIAGRAM TO ASTM C1399



Appendix I: Residual Strength to ASTM C1399 for Wet-Mix Shotcrete Mix WSF (Microsynthetic Fiber

CANADIAN GREENFIELD TECHNOLOGIES CORP.
Mr. Mike Pildysh, M.Eng., P.Eng, President
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LZhang File No: 11VA062
Date: 28-Mar-16

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation

SUBJECT: Flexural Performance of Microsynthetic Fiber-Reinforced Wet-Mix Shotcrete to ASTM C 1399 - 10

	Initial Loading		Reloading										
				Residual Load (kN)					Residual Strength (MPa)				
Sample No.	**Peak Load (kN)**	**Deflection at Peak Load (mm)**	**Peak Load at Reloading (kN)**	**$P_{100,0.5}$****	**$P_{100,0.75}$**	**$P_{100,1.0}$**	**$P_{100,1.25}$**	**Average Residual Load (kN)**	**$f_{100,0.5}$*****	**$f_{100,0.75}$**	**$f_{100,1.0}$**	**$f_{100,1.25}$**	**Average Residual Strength (MPa)**
WSF-1	23.59	0.049	1.10	1.37	1.23	1.09	1.00	1.17	0.40	0.36	0.32	0.29	0.34
WSF-2	24.70	0.050	1.41	1.34	1.24	1.16	1.10	1.21	0.40	0.37	0.35	0.33	0.36
WSF-3	28.23	0.051	1.13	1.12	1.08	1.04	0.91	1.04	0.33	0.32	0.31	0.27	0.31
AVG.	**25.51**	**0.050**	**1.21**	**1.28**	**1.18**	**1.10**	**1.00**	**1.14**	**0.38**	**0.35**	**0.32**	**0.30**	**0.34**

* $P_{100,0.5}$ is the residual load at 0.5 mm deflection

** $f_{100,0.5}$ is the residual strength at 0.5 mm deflection

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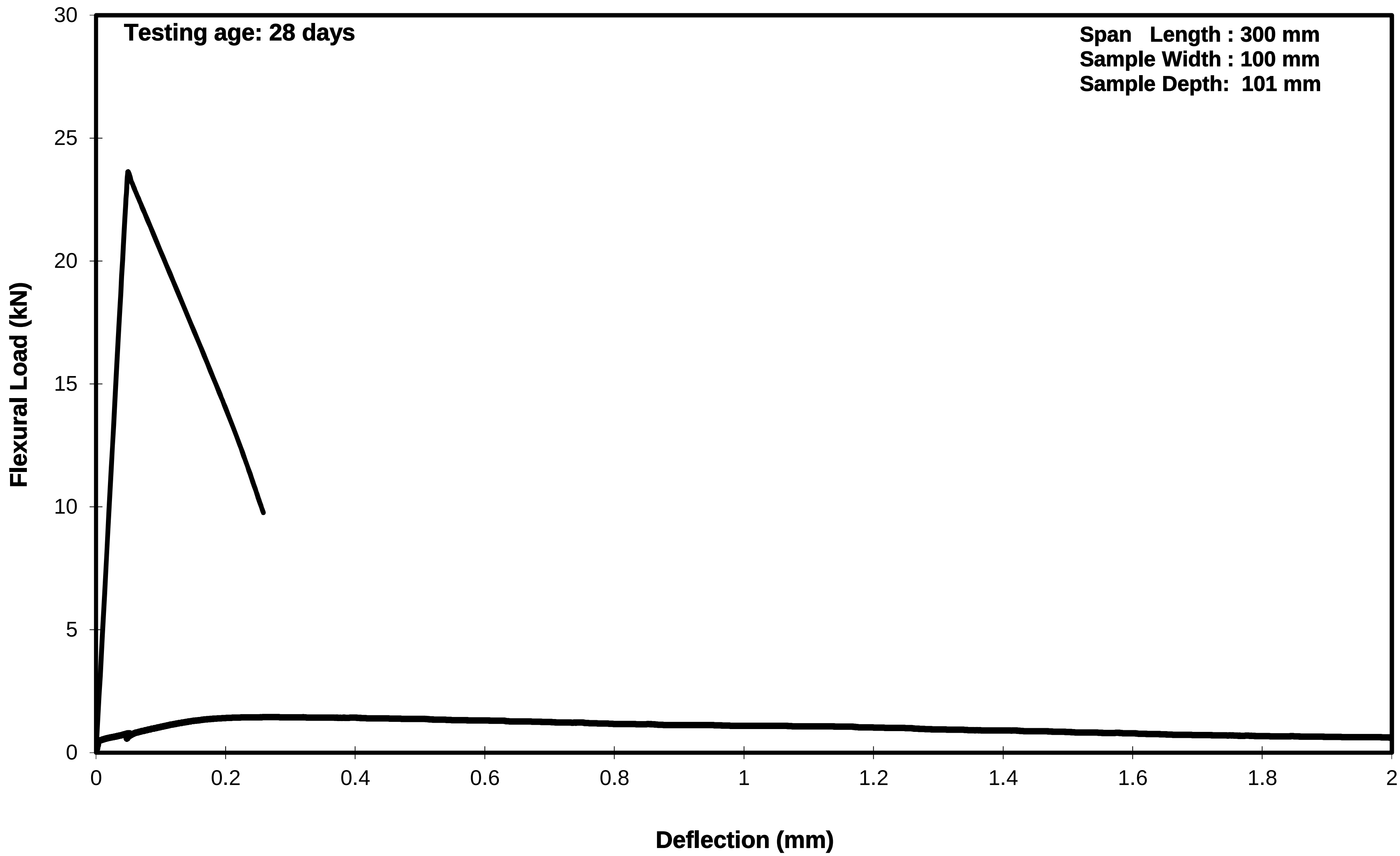
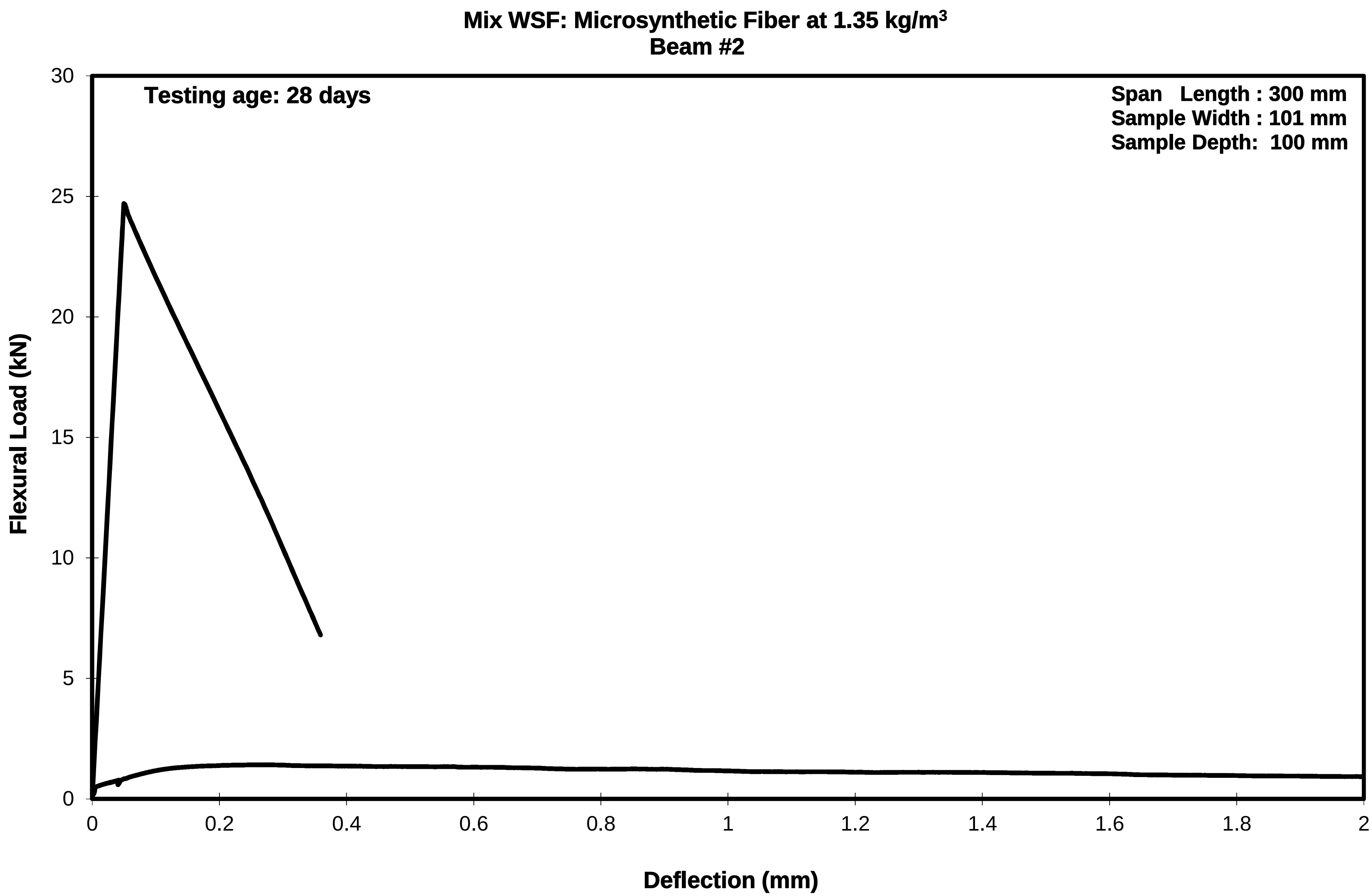
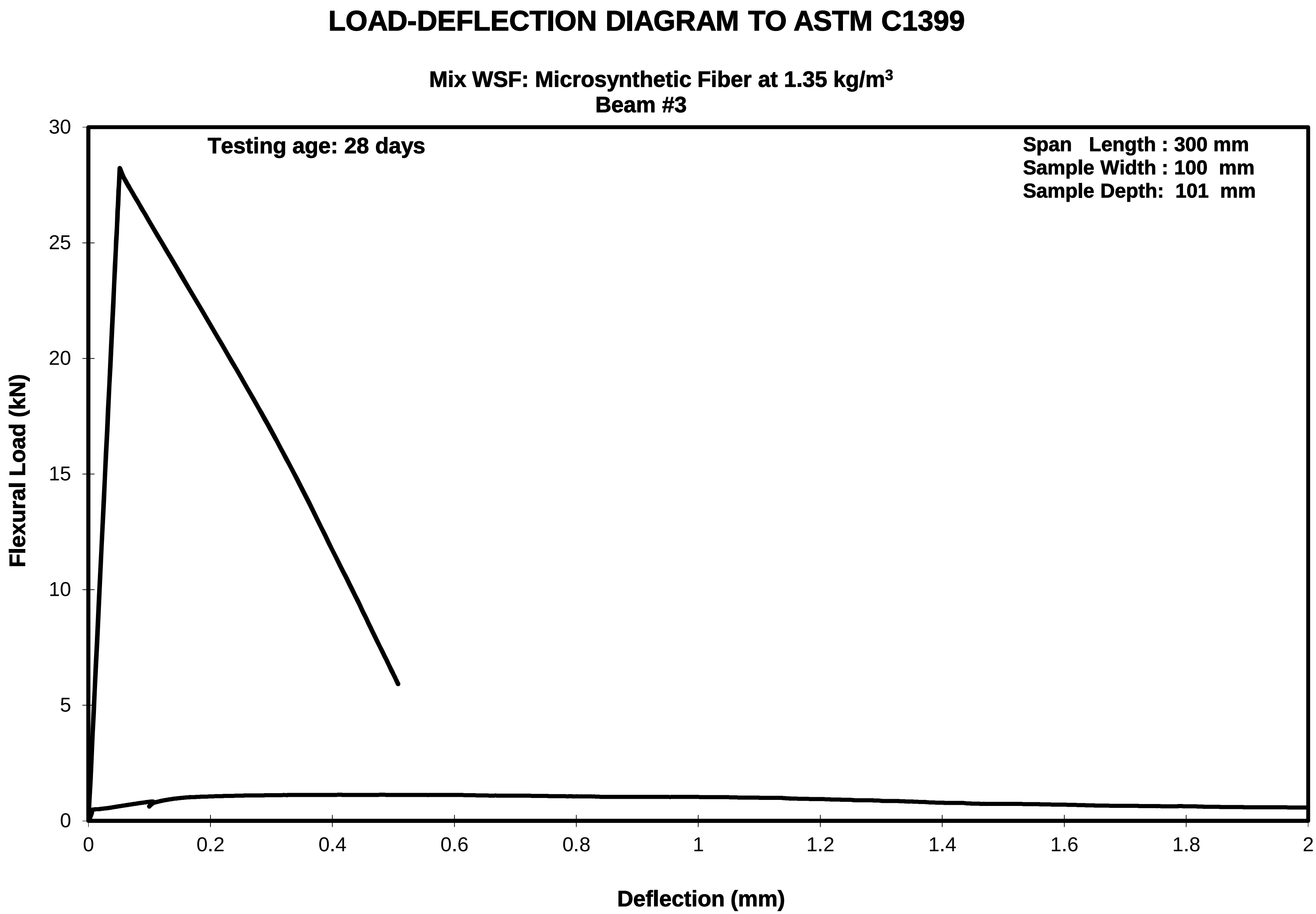
LOAD-DEFLECTION DIAGRAM TO ASTM C1399

Mix WSF: Microsynthetic Fiber at 1.35 kg/m^3
Beam #1



LOAD-DEFLECTION DIAGRAM TO ASTM C1399




LOAD-DEFLECTION DIAGRAM TO ASTM C1399
Mix WSF: Microsynthetic Fiber at 1.35 kg/m3
Beam #3
Testing age: 28 days
Span Length : 300 mm
Sample Width : 100 mm
Sample Depth: 101 mm
Flexural Load (kN)
Deflection (mm)
0
5
10
15
20
25
30
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2