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Evaluation of NForce-Fiber in Dry-Mix Shotcrete

Interim Report

Submitted to:

CANADIAN GREENFIELD TECHNOLOGIES CORP.

Submitted by:

LZhang Consulting & Testing Ltd

Vancouver, BC

April 5 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 dry-mix shotcrete. The Phase I study, i.e., *"Product Study and Due Diligence Phase"* involves evaluation of the behaviour and performance of dry-mix shotcretes made with NForce-Fiber compared to plain dry-mix shotcrete mixes with no fiber addition and a dry-mix shotcrete mix with microsynthetic fibre. The Phase I work for dry-mix shotcrete trial shoot was conducted at the Basalite Concrete Products Ltd (Basalite) yard in Surrey, BC, on February 28, 2016. Hardened shotcrete testing was conducted at the LZhang Consulting & Testing Ltd. (LZhang) laboratories in Richmond and Vancouver, BC from February 28, 2016 up to the date when this interim report was prepared.

2.0 DRY-MIX SHOTCRETE MIXTURE DESIGNS

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

Table 1. Dry-Mix Shotcrete Mixtures

Mix Type	Shotcrete Designation	Fiber Content	
		(kg/ m^3)	(% volume)
Plain	DP	0	0
NForce-Fiber	DNF	2	0.15
Microsynthetic Fiber	DSF	1.35	0.15

The dry-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 dry-mix shotcrete mixture designs for all the mixes also represent the most commonly used dry-mix shotcretes in the industry, including swimming pool shotcrete, repair and rehabilitation and shoring. The dry-mix shotcrete mix designs contained 20% fly ash by mass of cementitious materials and were based on mixes used in a comprehensive study of 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

The shotcrete subcontractor, LRutt Contracting Ltd (LRutt) used an Aliva dry-mix system that has a predampener and Aliva Rotary gun and a 850 cfm air compressor with an oil and water trap for application of the dry-mix shotcrete. A 50 mm internal diameter braided rubber hose connected to a Reed plastic nozzle was used. Potable water from the municipal water supply was added at the nozzle. The dry-bagged shotcrete mixture was predampened before discharge into the gun. The amount of water required for application of the shotcrete at the *wettest stable consistency* was established by the ACI Certified Nozzleman, (Mr. Shawn Ellis), shooting outside the rebound test chamber, before shooting one test panel for measurement of temperature development, and then two standard shotcrete test panels. This was followed by conducting thickness of vertical build-up and vertical rebound tests in the rebound chamber. Overhead rebound testing was also conducted by shooting an overhead panel with reinforcement (Fig. B-13)

All the ingredient materials, including ggregates, cement and fly ash were the same materials as those used in a previous study for CGT for mixing concrete in LZhang's laboratory and the same materials as those used for wet-mix shotcrete batching and shooting. Fibers were pre-mixed into the pre-bagged materials. Dry-mix shotcrete was applied by an ACI certified nozzleman. Plastic shrinkage test panels were shot and moved to Basalite's laboratory for plastic shrinkage testing to ASTM C1579 [Ref. 3]. Test panels were also shot for core extraction and testing. At age two days, all test panels were moved to cut beams for flexural toughness testing (Fig. B-22 & B-23) and cores were extracted for compressive strength testing (7 and 28 days). All the beam and core samples were cured in laboratory conditions of 23+/-2 ^{0}C, and 50% relative humidity until the age of testing.

Both vertical and overhead rebound testing were conducted for NForce-Fiber reinforced dry-mix shotcrete and microsynthetic fiber reinforced dry-mix shotcrete. For the overhead rebound test, a panel was provided with a 1 m square grid of 15M rebar at 100 mm on centre each way, offset from the soffit by 50 mm, and connected to vertical anchors coming through the overhead form. Photos for field predampening, shooting and rebound testing are included in Appendix B.
It should be noted that due to logistics reasons, the plain dry-mix shotcrete material was not batched and shot on 28 February, 2016. It is planned to finish the plain dry-mix shotcrete trial shoot and testing at a later date. All tests, except the overhead rebound testing, will be conducted for the plain dry-mix shotcrete. A final report will be issued for the dry-mix shotcrete when this testing is completed.

3.2 Plastic Shotcrete Tests

Dry-Mix shotcrete temperature and as-shot air content were tested. Test results are reported in Appendix C and are summarized in Table 2 which follows.

Table 2. Dry-Mix Shotcrete Plastic Properties

Mixture	Fiber Content		As-Shot Air Content (%)	Shotcrete Temperature (°C)
	(kg/m^3)	(% volume)		
DNF	2	0.15	3.5	8.0
DSF	1.35	0.15	3.4	8.0

The as-shot air content for both mixes DNF and DSF are within the specified 3.0-6.0% range. This is consistent with the air content requirements for the shotcrete industry [Ref 4].

3.3 Shootability, cohesiveness, vertical thickness build up and rebound

Both dry-mix shotcrete mixtures were found to be readily shootable. No hose plugs or blockages occurred. Both dry-mix shotcrete mixtures were able to build up vertical thickness of up to 150 mm (6") but with different shooting characteristics. The NForce-Fiber reinforced Dry-Mix shotcrete was found to be very cohesive during shooting. The mix adhered well to the vertical sealed plywood form and could be cut and trimmed with a steel trowel without sagging or sloughing (Fig. B-9). Also, there was very little separation of the NForce-Fibers from the shotcrete stream during shooting. This was apparent in the low amount of fiber observed in the rebound materials. After shooting, it was noted that a small amount of NForce-Fiber was left on the predampener hopper grid (Fig. B-12 & B-13). These fibers were collected and weighed. They represented about 0.56%

of the total NForce-Fiber mass in the mixture. Therefore, the wastage of NForce-Fiber during shooting is considered negligible.

It should be noted that when the microsynthetic fiber dry-mix shotcrete was applied, a considerable amount of the microsynthetic fiber was blown out in the air and deposited on the floor, without being properly incorporated into the receiving surface (Fig. B-14 to B-16). This is attributed to the fact that microsynthetic fiber, with a specific gravity of 0.92, is lighter and easier to separate from the shotcrete stream during shooting. Also, the hydrophobic characteristics of the microsynthetic fiber (compared to the hydrophyllic characteristics of the NForce-Fiber) also likely played a role in this segeration of the microsynthetic fiber from the shotcrete stream during shooting.

Both vertical and overhead rebound testing was conducted inside the rebound chamber. Table 3 list test results. These results (with the exception of the DSF overhead test result) are typical of results expected for dry-mix shotcrete industry. It appears that both NForce-Fiber and microsynthetic fiber reinforced dry-mix shotcrete have the similar vertical rebound, while the mix DNF with NForce-Fiber has a substantially lower overhead rebound value.

Table 3. Rebound Testing Results for Dry-Mix Shotcrete Mixtures

Mixture	Fiber Content		Vertical Rebound	Overhead Rebound
	(kg/m^3)	(% volume)		
DP	0	0	TBP	TBP
DNF*	2	0.15	33.6%	37.0%
DSF	1.35	0.15	32.9%	59.3%**

TBP = to be provided when mix DP tests completed

* NForce-Fiber left in hopper grid is 0.56% by mass of total fiber batched

** Rebound appears excessive and test result not considered reliable

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)*[3]. Two panels were shot, finished and tested for each Dry-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 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 sample was tested to determine the set time to ASTM C403. Once the concrete sample 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 are summarized in Table 4 as follows:

Table 4. Plastic Shrinkage Testing Results for Dry-Mix Shotcrete Mixtures

Mixture	Fiber Content		Crack Width (mm)	Crack Reduction Ratio (CRR), %
	(kg/m^3)	(% volume)		
DP	0	0	TBP	N/A
DNF	2	0.15	0.75	TBP
DSF	1.35	0.15	0.75	TBP

TBP = to be provided when mix DP tests completed

Table 4 shows that when NForce-Fiber was added at 2.0 kg/m^3, i.e., 0.15% by volume, the crack width is the same as of the microsynthetic fiber, both of which were 0.75 mm. Although no value is yet available for the plain dry-mix shotcrete, the shrinkage cracking reduction performance for both the NForce-Fiber and microsynthetic fiber appear to be the same.

3.5 Finishability

After samples were shot, no evidence of sedimentation, segregation or bleeding was observed in any of the mixes. Dry-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 with fibers, are provided in Appendix E.

The mix with microsynthetic fiber (mix DSF), 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 (mix DNF)) displayed superior finishing characteristics to microsynthetic fiber shotcrete (DSF) mix. The NForce-Fiber appeared to act as a “finishing aid”, providing the mixes with a greater cohesiveness, which resulted in relatively smoother textured surface finishes for all of the finishing tools used, particularly when compared to the DSF mix. Virtually no fibers were evident in the finished surface of DNF 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 SHOTCRETE 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 All Dry-Mix Shotcrete Mixtures

Mixture	Fiber Content		7 Days Compressive Strength (MPa)	28 Days Compressive Strength (MPa)
	(kg/m^3)	(% volume)		
DP	0	0	TBP	TBP
DNF	2	0.15	51.2	61.5
DSF	1.35	0.15	43.0	53.7

TBP = to be provided when mix DP tests completed

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 meet the specified strength requirement.
It should be noted that the compressive strength for mix DNF, i.e., concrete mixture with 2.0 kg/m^3 NForce-Fiber, has a higher compressive strength than the microsynthetic fiber mixture.

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 as follows:

Table 6. Boiled Absorption and Volume of Permeable Voids

Mixture	Fiber Content		Boiled Absorption (%)	Volume of Permeable Voids (%)
	(kg/m^3)	(% volume)		
DP	0	0	TBP	TBP
DNF	2	0.15	5.8	12.9
DSF	1.35	0.15	5.3	11.9

TBP = to be provided when mix DP tests completed

Results for boiled absorption and volume of permeable voids, as listed in Table 5, show that both mixes have BA and VPV values well below the maximum BA of 8% and maximum VPV of 17% as per ACI 506 Guide of Shotcrete [Ref. 5]. The mixes with microsyntehtic fiber and NForce-Fiber have similar BA and VPV values.

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 will be added in Appendix H when they become available.

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 7 as follows.

Table 7. Flexural Strength, Flexural Toughness and Residual Flexural Strength

Mixture	Fiber Content		Flexural Strength to ASTM C1609 (MPa)	Flexural Toughness to ASTM C1609 (MPa)	Residual Flexural Strength to ASTM C1399 (MPa)
	(kg/m^3)	(% volume)			
DP	0	0	TBA	TBP	TBP
DNF	2.0	0.15	6.14	0.0	0.09
DSF	1.35	0.15	6.02	0.0	0.00

TBP = to be provided when mix DP tests completed

Table 7 shows that mix DNF with NForce-Fiber has a similar flexural strength to mix DSF with microsyntehtic fiber, when tested to ASTM C1609.

The flexural toughness for both NForce-Fiber reinforced dry-mix shotcrete and microsynthetic fiber reinforced dry-mix shotcrete in the ASTM C1609 test are zero. This is due to the fact that the beams fracture into two components at the peak load. The residual flexural strength, when tested to ASTM C1399 for NForce-Fiber, is 0.09 MPa at an addition rate of 2.0 kg/ m^3. The residual flexural strength for the microsynthetic fiber reinforced concrete is 0 MPa at an addition rate of 1.35 kg/ m^3. This shows that the residual flexural strength for mix DNF with NForce-Fiber at 2.0 kg/ m^3 is slightly higher than for the mix DSF with microsynthetic fiber at 1.35 kg/ m^3, which is the same fiber addition rate by % volume.

5 DISCUSSION

To be provided when all test results are available.

6 RECOMMENDATIONS

To be provided when all test results are available.

LZhang thanks you for this opportunity to have been of service. We trust this report satisfies your requirements. Should you have any questions, please contact the undersigned.

Respectfully submitted,

by LZhang Consulting & Testing Ltd

Reviewed by

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1. CSA A23.1/23.2-2014. “Concrete materials and methods of concrete construction/Test methods and standard practices for concrete.” 2014. Canadian Standard Association. Toronto, ON Canada. 691 pp
2. L. Zhang., D.R. Morgan., S. Mindess “Comparative Evaluation of the Transport Properties of Shotcrete Compared to Cast-in-Place Concrete”, ACI Materials Journal, (accepted for publication).
3. ASTM C1579-2009 Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert).
4. L. Zhang., “Testing Air Content of Dry-Mix Shotcrete”. Shotcrete Magazine, Spring 2015, pp 22-24.
5. ACI 506-05.R Guide to Shotcrete, American Concrete Instituate (ACI). 2005.

Appendix A: DRY-MIX SHOTCRETE MIX DESIGN Mix DP (Plain Dry-Mix Shotcrete)

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

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation
SUBJECT: Mix DP (Plain Dry-Mix Shotcrete)

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
Estimated Water, L		180	1000	0.1800
NForce Fiber**		0.000	1480	0.0000
Air-Entraining Admixture*		0.110	1010	0.0000
Air Content:	At pump +/- 1.5%	7-10%	-	-
Air Content:	As shot +/- 1.5%	4.5	-	0.0450
Total		2350	Yield (m^3)=	1.0154

NOTES
* Air entraining admixture added during batching at dosage required to produce required air content

PROJECT REQUIREMENTS

Minimum Compressive Strength	30 MPa at 7 days, 40 MPa at 28 days
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)	2315
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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Reviewed by: D.R. Morgan, Ph.D., P.Eng
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Appendix A: DRY-MIX SHOTCRETE MIX DESIGN Mix DNF (NForce-Fiber Dry-Mix Shotcrete)

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

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation

SUBJECT: Mix DNF (NForce-Fiber Dry-Mix Shotcrete)

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
Estimated Water, L		180	1000	0.1800
NForce Fiber**		2.000	1480	0.0014
Air-Entraining Admixture **		0.130	1010	0.0000
Air Content:	At pump +/- 1.5%	7-10%	-	-
Air Content:	As shot +/- 1.5%	4.5	-	0.0450
Total		2352	Yield (m^3)=	1.0168

NOTES

* Specific Gravity of NForce fiber is provided by Canadian Greenfield Technologies Corp.
** Air entraining admixture added during batching at dosage required to produce required air content

PROJECT REQUIREMENTS

Minimum Compressive Strength	30 MPa at 7 days, 40 MPa at 28 days
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
Materials Engineer
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Reviewed by: D.R. Morgan, Ph.D., P.Eng
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Appendix A: DRY-MIX SHOTCRETE MIX DESIGN Mix DSF (Microsynthetic Fiber Dry-Mix Shotcrete)

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

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation
SUBJECT: Mix DSF (Microsynthetic Fiber Dry-Mix Shotcrete)

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
Estimated Water, L		180	1000	0.1800
Interstar Microsynthetic Fiber		1.350	920	0.0015
Air-Entraining Admixture *		0.125	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)=	1.0169

NOTES
* Air entraining admixture added during batching at dosage required to produce required air content

PROJECT REQUIREMENTS

Minimum Compressive Strength	30 MPa at 7 days, 40 MPa at 28 days
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)	2312
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 dry-mix shotcrete shooting

Figure B-1: Pre-bagged materails (0.5 yd^3) discharged into the hopper, then discharged by an auger into the predampener: water added to predampen the materials to moisture content of 4-6%, and materials discharged into an Aliva rotary gun.

Figure. B-2: Setup for dry-mix shooting, including vertical and overhead rebound chamber, and test panels.

Figure B-3: Dry-Mix shotcrete rebound test set-up

Overhead rebound test: 1m square grid of 15M rebar at 100mm on centre each way, offset from soffit by 50mm, and connected to vertical anchors coming through the overhead form.

Vertical rebound test: sealed plywood fixed to the lock block concrete wall.

Figure B-4: Shooting test panels

Figure B-5: Shooting panel for plastic shrinkage test

Figure B-6: Shooting vertical build-up

Figure B-7: Vertical build up with NForce-Fiber (2.0 kg/m^3) reinforced dry-mix shotcrete

Figure B-8: Measuring the vertical thickness build-up of dry-mix shotcrete

Figure B-9: Cutting off the vertical dry-mix shotcrete build-up

Figure B-10, Cutting off the vertical dry-mix shotcrete build-up

Figure B-11: NForce-Fiber reinforced dry-mix shotcrete after shoot

Figure B-12: NForce-Fiber retained on the grid of the hopper during shooting.

Figure B-13: NForced-Fiber retained on the hopper grid, a total weight of 8.5 gram, which is 0.56% by mass of the total batched fiber

Figure B-14: Shooting microsythetic fibre reinforced dry-mix shotcrete, note that the fibers were blown out, deposited on the floor and not incorporated into the panel

Figure B-15: Rebound test for microsynthetic fiber reinforced dry-mix shotcrete. Note that a significant amount of microsythetic fibers were blown out during shooting and not incorporated into the dry-mix shotcrete.

Figure B-16: Close look at the rebound for microsynthetic fiber reinforced dry-mix shotcrete

Figure B-17: Shooting overhead rebound test

Figure B-18: Overhead shotcrete build-up for rebound test

Fig. B-19, Shooting into bucket to test as-shot air content

Figure B-20: Cleaning hopper after each mixture shot to avoid cross-containmanation of mixes.

Figure B-21: Cleaning overhead rebound panel after each shoot

Figure B-22: Test panels saw-cut to produce beams

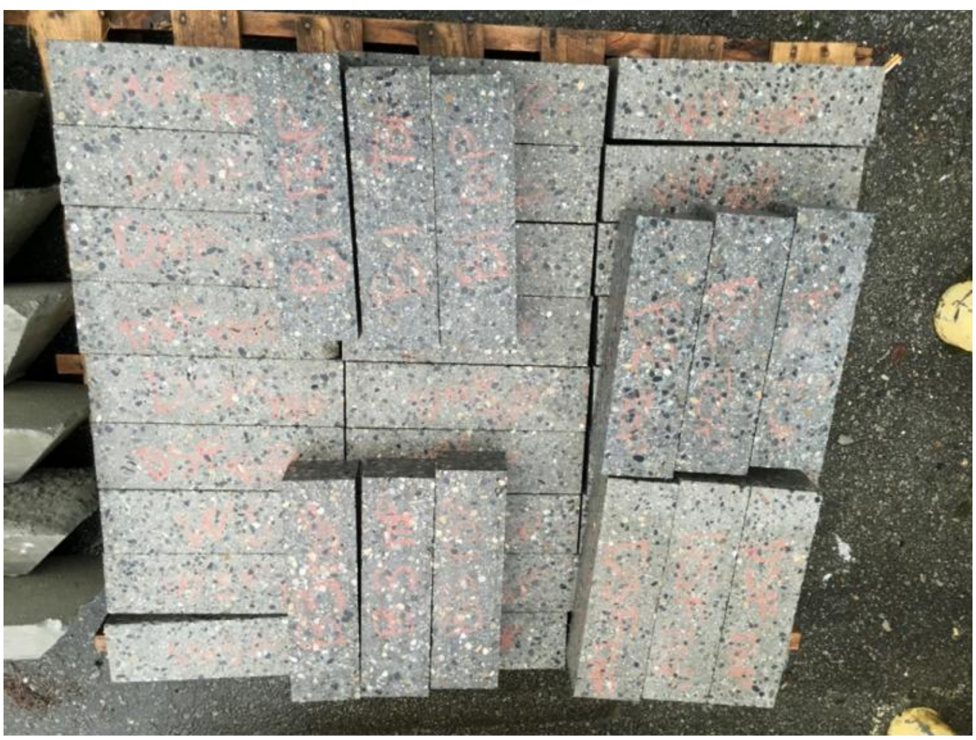

Figure B-23 Beams cut to 100 +/- 2 mm for ASTM C1609 & ASTM C1399 tests

Appendix C: Plastic Properties

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

PROJECT: NForce-Fiber Reinforced Shotcrete Evaluation

SUBJECT: Shotcrete Plastic Properties

Date Shot: 28-Feb-16 **Dry-Mix Fiber Reinforced Shotcrete** **Ambient Temperature:** 5 ^oC

Mixture	Fiber Content (kg/m^3)	Fiber Content (% volume)	As-Shot Air Content (%)	Shotcrete Temperature (^{o}C)	Evaporation Rate (kg/m^2.h) in ASTM C1579 Test
DNF	2	0.15	3.5	8.0	1.35
DSF	1.35	0.15	3.4	8.0	1.35

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

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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		Panel #	Crack Width (mm)	Crack Reduction Ratio (CRR), %
		(kg/m^3)	(% volume)			
DP	**28-Feb-16**	Plain Dry-Mix Shotcrete	0	Panel #1	To be added	
				Panel #2		
				Average		
DNF		NForce-Fiber, 2.0	0.15	Panel #1	0.75	To be added
				Panel #2	0.75	
				Average	0.75	
DSF		Microsynthetic fiber, 1.35	0.15	Panel #1	0.5	
				Panel #2	1.0	
				Average	0.75	

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Figure D-1 & D-2 : Plain dry-mix shotcrete panel #1, 0 kg/m^3 fiber, Photos to be added

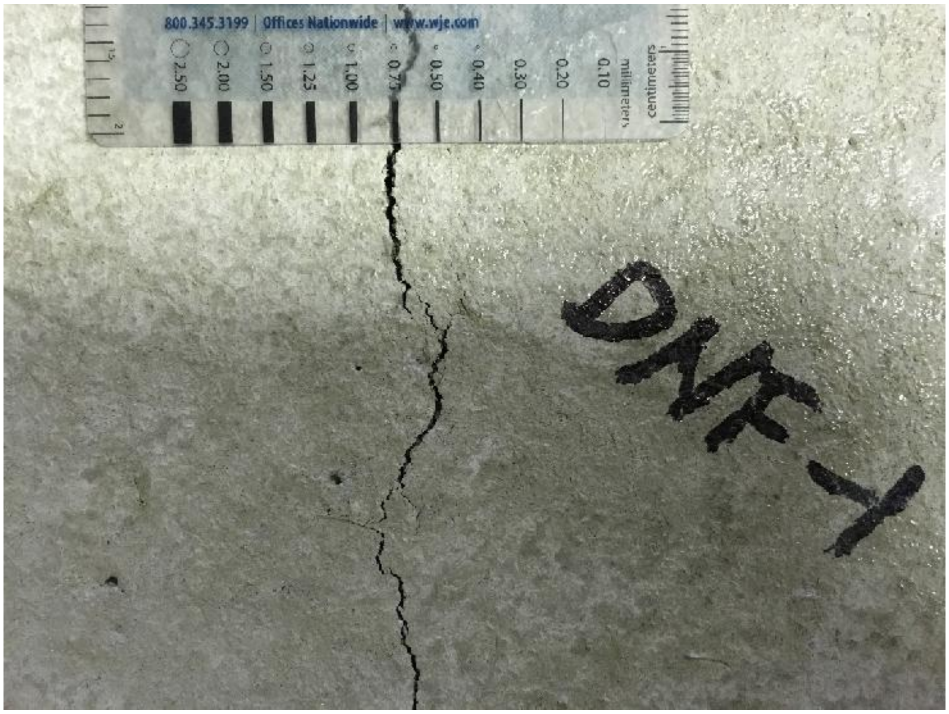

Figure D-3: NForce-Fiber panel #1, 2 kg/m^3 fiber, 0.75 mm crack width

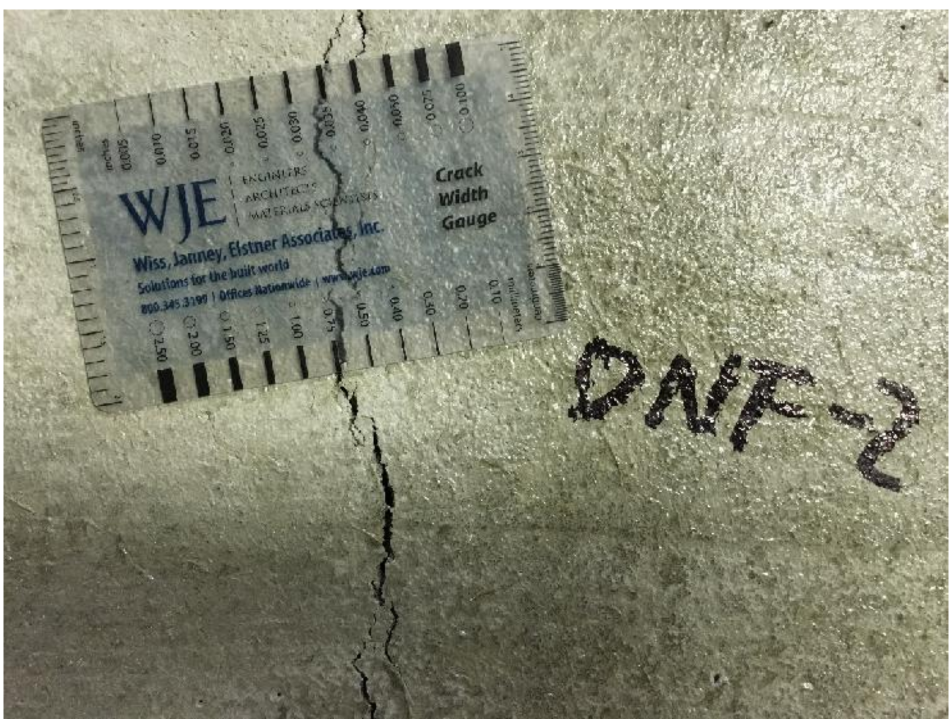

Figure D-4: NForce-Fiber panel #2, 2 kg/m^3 fiber, 0.75 mm crack width

Figure D-5: Microsynthetic fiber panel #1, 1.35 kg/m^3 fiber, crack width of 0.50 mm

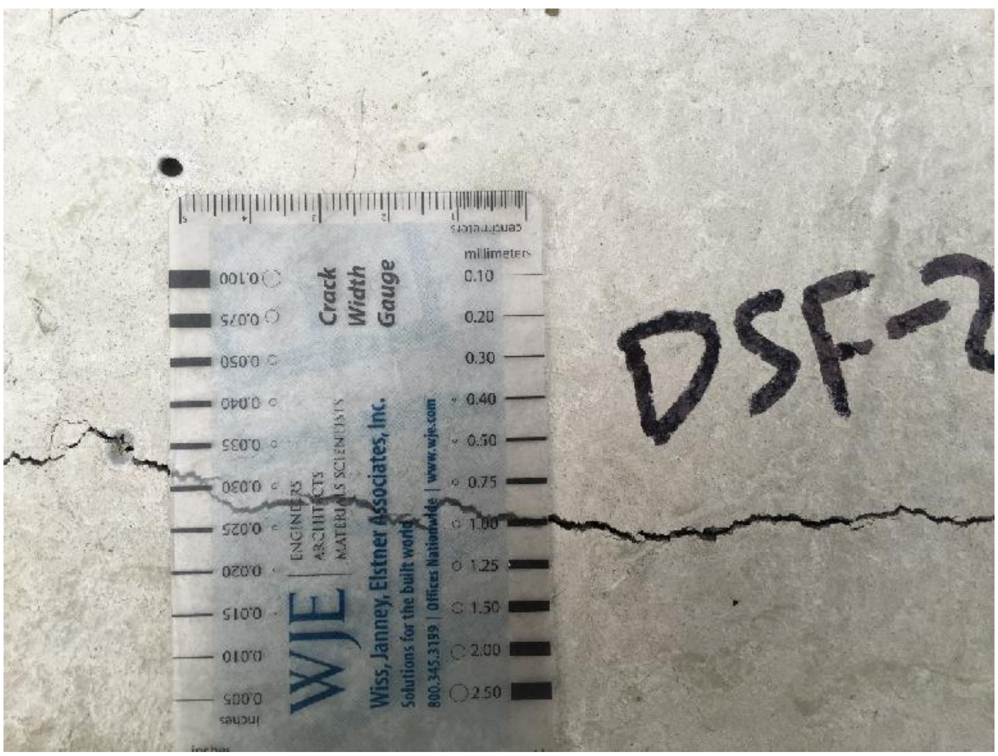

Figure D-6: Microsynthetic fiber panel #2, 1.35 kg/m^3 fiber, crack width of 1.0 mm

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-8: Microsynthetic fiber dry-mix shotcrete finish: steel trowel finish

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

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

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

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

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

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

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

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

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

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

Figure E-19: NForce-Fiber dry-mix shotcrete finish: sponge float finish

Appendix F: Compressive Strength for Dry-Mix Shotcrete

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LZhang File No: 11VA062
Date: 27-Mar-16

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

SUBJECT: **Compressive Strength for Dry-Mix Shotcrete Cores to ASTM C1604**

Date Shot: 28-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)								
DNF	**2.0**	**0.15**	7	247.5	74.8	56.4	109.6	1.47	53.5	**51.2**
				225.5	74.5	51.7	109.0	1.46	49.1	
				232.7	74.4	53.5	108.2	1.45	50.8	
			28	289.6	74.4	66.6	106.4	1.43	63.3	**62.5**
				286.7	74.4	65.9	109.0	1.46	62.6	
				282.0	74.4	64.9	108.5	1.46	61.6	
DSF	**1.35**	**0.15**	7	191.0	74.3	44.0	112.0	1.51	41.8	**43.0**
				195.6	74.4	45.0	108.5	1.46	42.8	
				203.0	74.4	46.7	111.3	1.50	44.4	
			28	249.5	74.4	57.3	100.4	1.35	53.9	**53.7**
				246.7	74.4	56.8	108.2	1.45	53.9	
				246.4	74.4	56.7	105.7	1.42	53.3	

Per:

Lihe (John) Zhang, Ph.D., P.Eng
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Appendix G: Boiled Absorption and Volume of Permeable Voids

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

LZhang
Consulting & Testing

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

Date of Shot: 28-Feb-16
Date Test: 28-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, %
DNF	NForce-Fiber, 2.0 kg/m^3	5.0	5.5	2.252	2.364	2.375	2.568	12.3
		5.3	6.1	2.233	2.352	2.368	2.582	13.5
		5.1	5.8	2.248	2.362	2.378	2.583	13.0
Average		**5.1**	**5.8**	**2.244**	**2.359**	**2.374**	**2.578**	**12.9**
DSF	Microsynthetic fiber, 1.35 kg/m^3	4.7	5.0	2.262	2.370	2.375	2.550	11.3
		5.1	5.6	2.249	2.364	2.375	2.574	12.6
		4.9	5.2	2.250	2.360	2.367	2.549	11.7
Average		**4.9**	**5.3**	**2.254**	**2.365**	**2.372**	**2.558**	**11.9**

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

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

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

PROJECT: NForce-Fiber Reinforced Dry-Mix Shotcrete Evaluation

SUBJECT: Flexural Performance of NForce-Fiber Fiber-Reinforced Dry-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)	$R_{100,\ 2.0}$
DNF (2.0)-1	23.21	6.61	0.039	Not applicable*					
DNF (2.0)-2	23.73	6.77	0.041						
DNF (2.0)-3	21.47	6.14	0.043						
AVG.	**22.80**	**6.51**	**0.041**						

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

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

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Calgary, AB
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LZhang File No: 11VA062
Date: 28-Mar-16

PROJECT: NForce-Fiber Reinforced Dry-Mix Shotcrete Evaluation

SUBJECT: Flexural Performance of Microsynthetic Fiber Fiber-Reinforced Dry-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)	$R_{100,\ 2.0}$
DSF (1.35)-1	20.25	5.99	0.039	Not applicable*					
DSF (1.35)-2	23.27	6.65	0.041						
DSF (1.35)-3	18.69	5.43	0.043						
AVG.	**20.74**	**6.02**	**0.041**						

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

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

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

PROJECT: NForce-Fiber Reinforced Dry-Mix Shotcrete Evaluation

SUBJECT: Flexural Performance of NForce-Fiber Reinforced Dry-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)**
DNF (2.0)-1	22.28	0.041	0.74	0.34	0.17	0.11	0.07	0.17	0.10	0.05	0.03	0.02	0.05
DNF(2.0)-2	24.93	0.054	0.49	0.30	0.23	0.13	0.08	0.19	0.09	0.07	0.04	0.02	0.05
DNF (2.0)-3	24.40	0.056	0.90	0.90	0.67	0.55	0.42	0.64	0.26	0.19	0.16	0.12	0.18
AVG.	**23.87**	**0.050**	**0.71**	**0.51**	**0.36**	**0.26**	**0.19**	**0.33**	**0.15**	**0.10**	**0.07**	**0.05**	**0.09**

* $P_{100,0.5}$ 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
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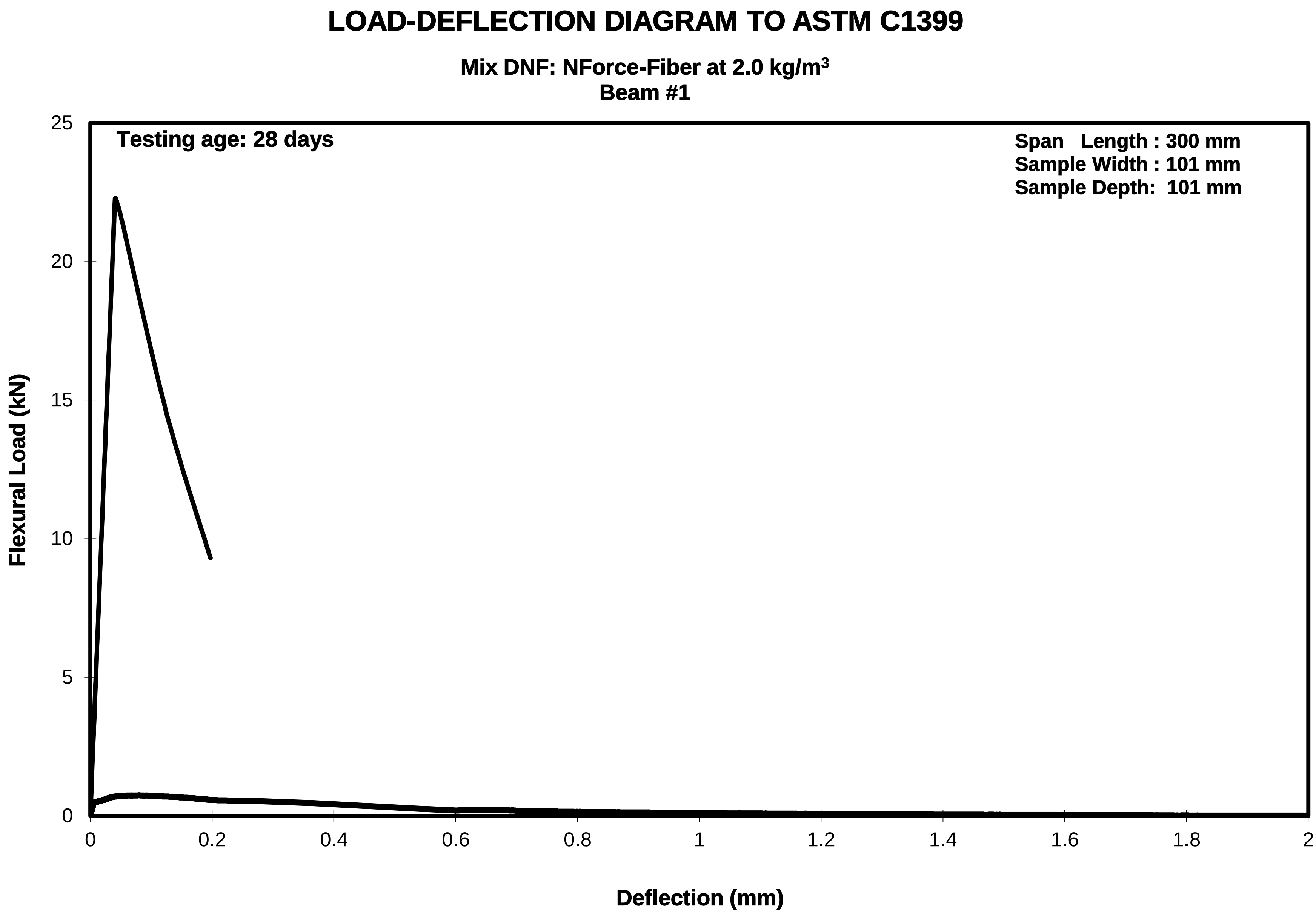
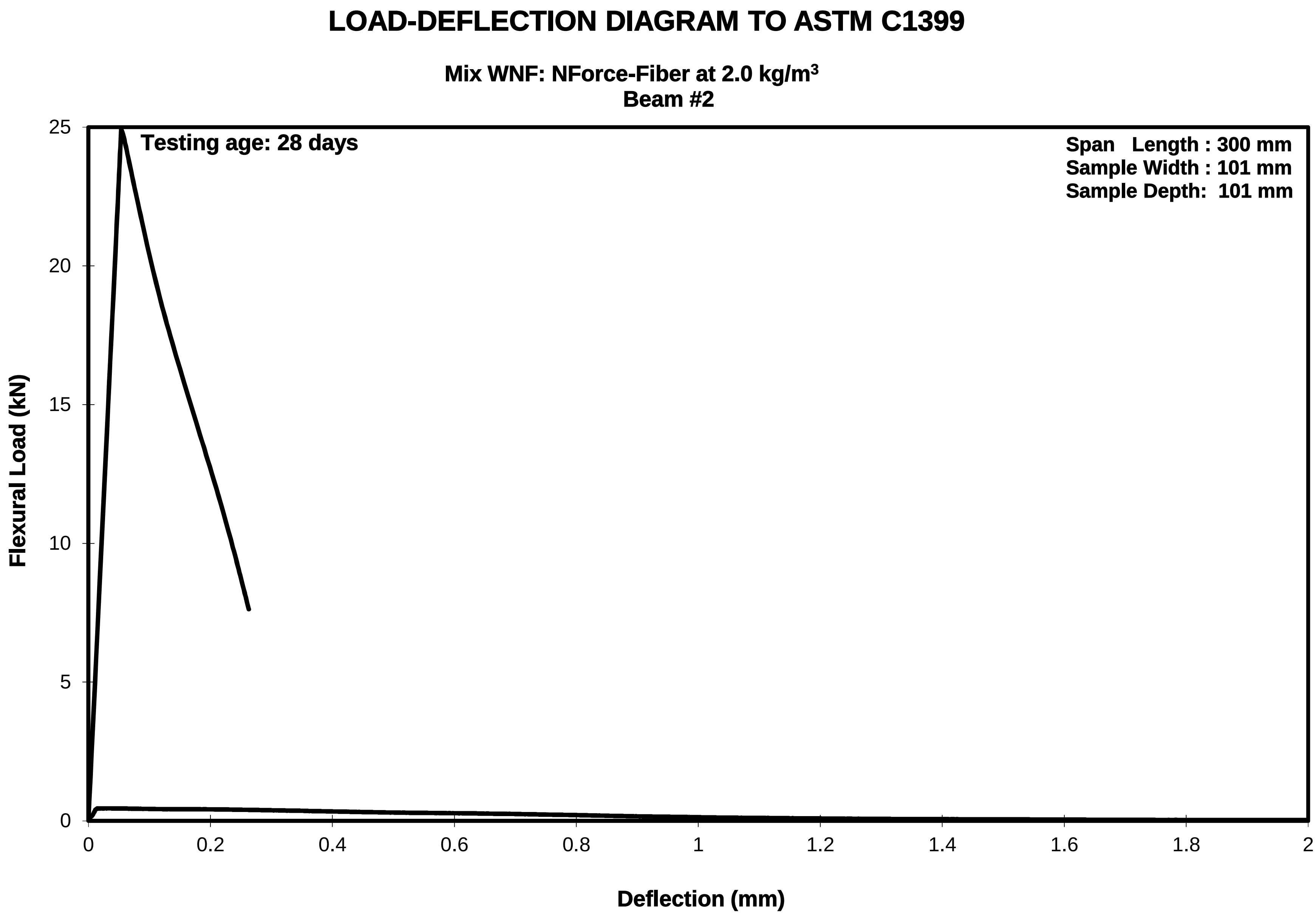
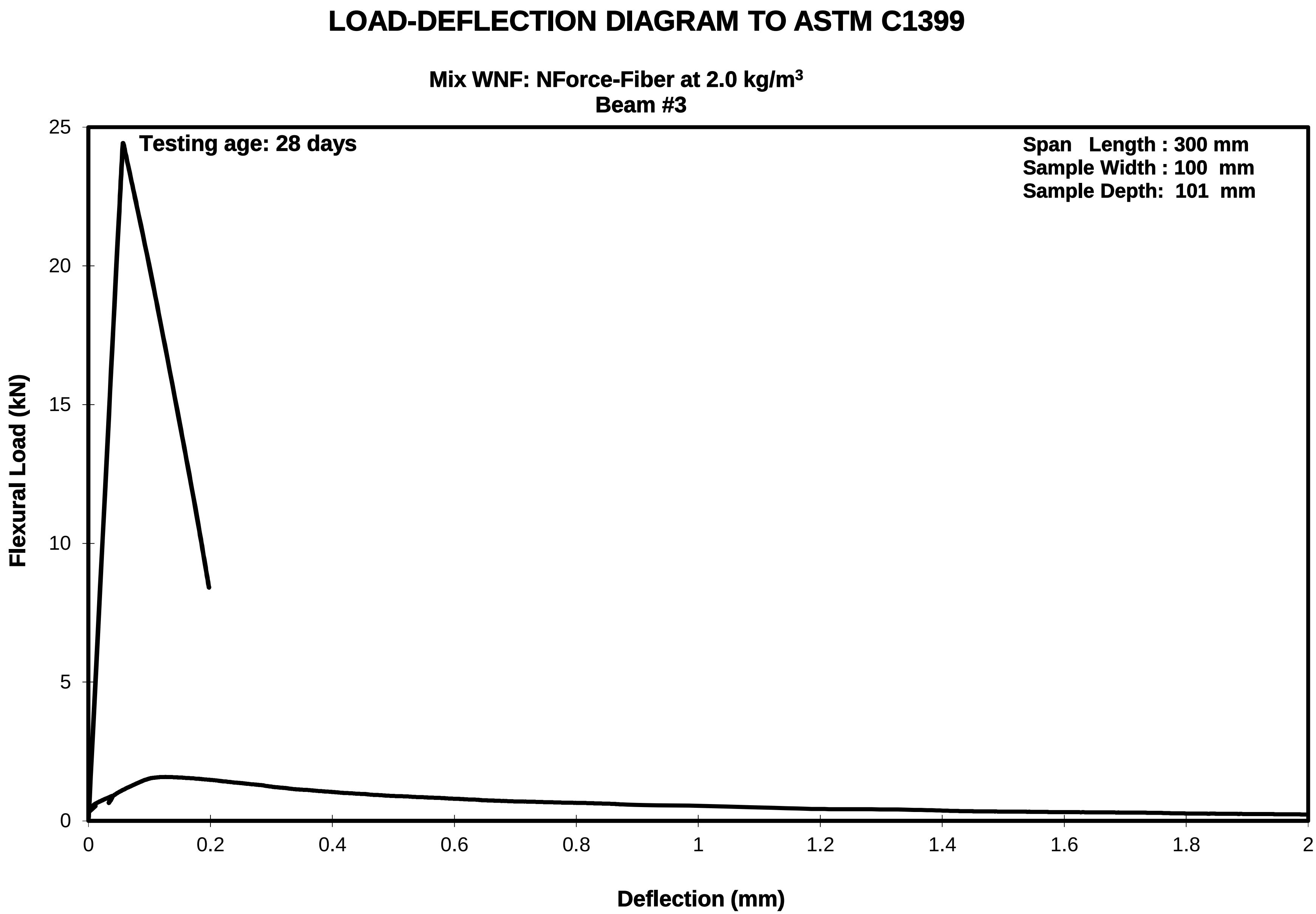

LOAD-DEFLECTION DIAGRAM TO ASTM C1399
Mix DNF: NForce-Fiber at 2.0 kg/m3
Beam #1
Testing age: 28 days
Span Length : 300 mm
Sample Width : 101 mm
Sample Depth: 101 mm
Flexural Load (kN)
Deflection (mm)
0
5
10
15
20
25
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


LOAD-DEFLECTION DIAGRAM TO ASTM C1399
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
25
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
Mix WNF: NForce-Fiber at 2.0 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
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Appendix I: Residual Strength to ASTM C1399 for Dry-Mix Shotcrete Mix DSF (Microsynthetic Fiber)

CANADIAN GREENFIELD TECHNOLOGIES CORP.
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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 Dry-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)
DSF-1	31.49	0.052	0.00										
DSF-2	27.86	0.059	0.00										
DSF-3	31.60	0.055	0.00										
AVG.	**30.32**	**0.055**	**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
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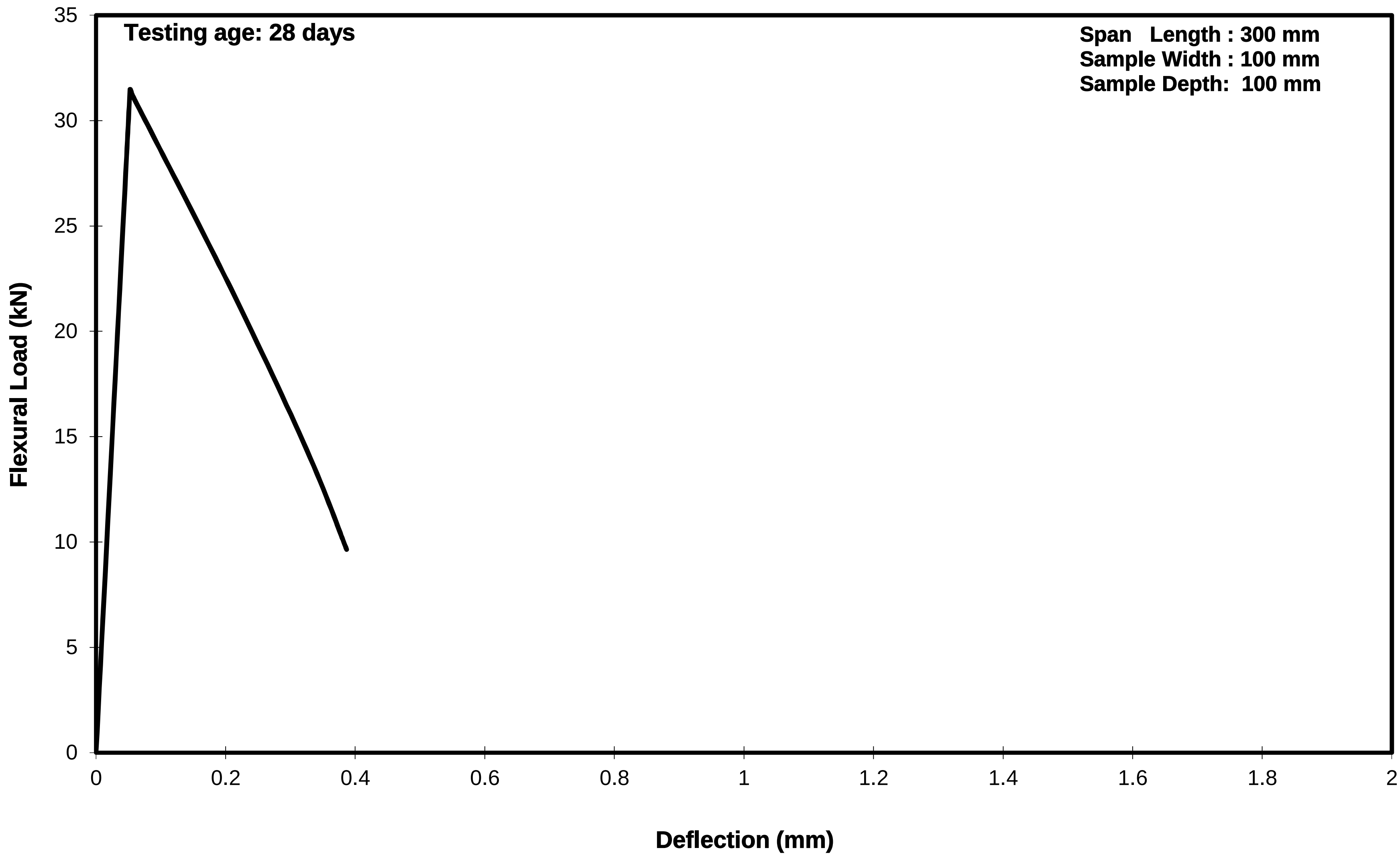
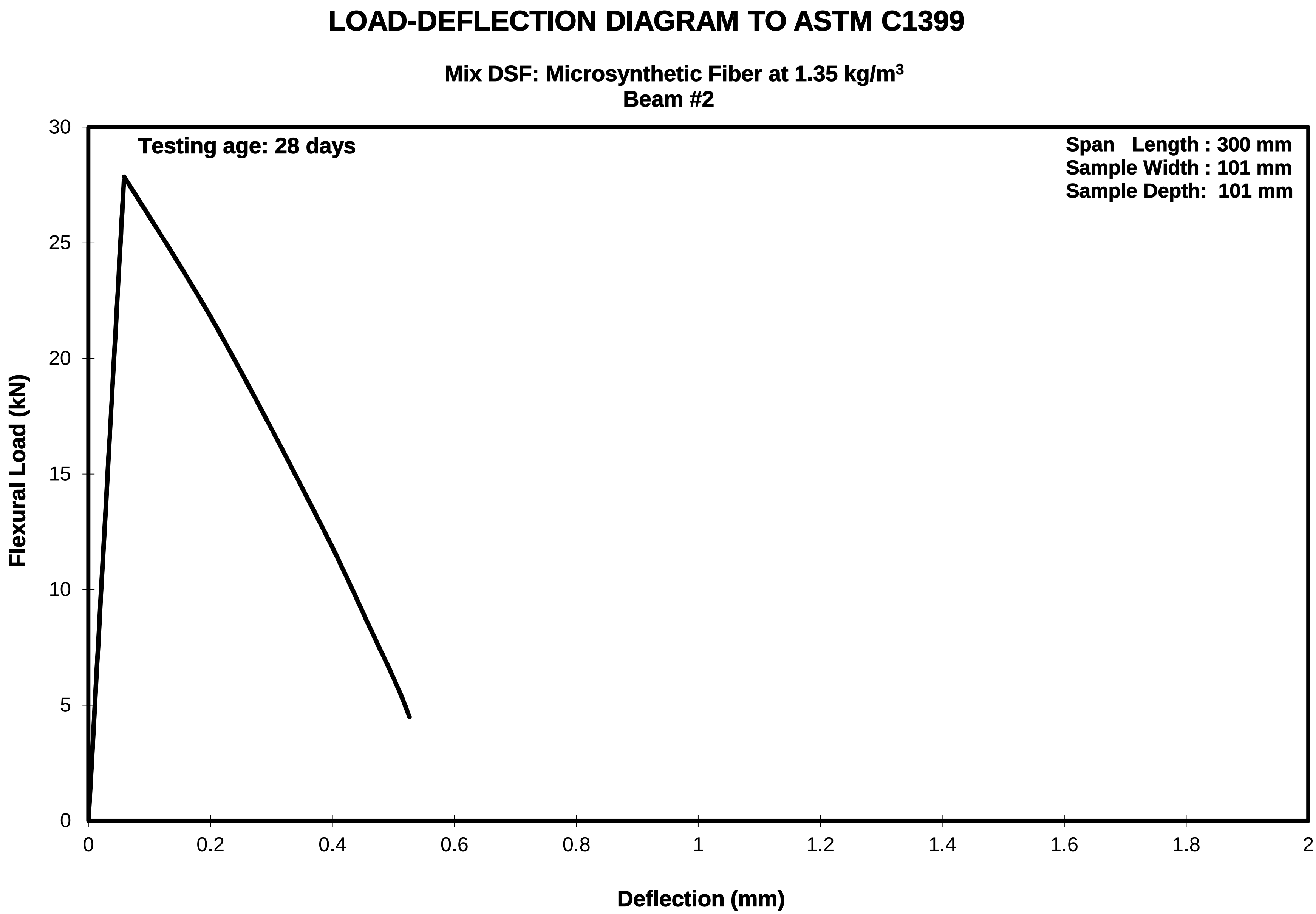
LOAD-DEFLECTION DIAGRAM TO ASTM C1399

Mix DSF: Microsynthetic Fiber at 1.35 kg/m³
Beam #1




LOAD-DEFLECTION DIAGRAM TO ASTM C1399
Mix DSF: Microsynthetic Fiber at 1.35 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
25
30
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