IN-SITU TESTING ON THE BOND STRENGTH OF 15 mm (#5) MST-BAR BARS TO HILTI HIT-RE 500 V3 ADHESIVE IN NORMAL AND FIBRE-REINFORCED CONCRETE

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May 25th, 2021

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1 Introduction

This report addresses the use of drill and bond 15 mm (#5) MST-BAR GFRP rebar to construct post-casted concrete plinths required on an existing bridge deck. A typical example would be for transforming a bridge deck into one that can accommodate train tracks. The report presents part of the data acquired in the approval process required by the Samuel-De Champlain Bridge Transit Corridor project. In this project, in-situ testing of the GFRP bars was necessary to understand the behaviour and expected bond strength.

The particular aspect of the tests conducted in this report is the oversize hole diameter with respect to the bar diameter. All tested bars were 15.9 mm (#5) in an oversize hole of 25.4 mm (1"). Typically, a hole is considered oversized if its diameter is larger by ¼" than the outer diameter of the bars. Hence, in this case, the testing was performed for an oversize hole that is approximately $1.5d_{bar}$. The embedment length for all MST-BAR GFRP rebars was taken as 125 mm.

2 Materials and Methods

2.1 Materials

2.1.1 GFRP Bars

The 15.9 mm (#5) MST-BAR GFRP rebars by B&B Manufacturing FRP Inc. compliant with CSA S807-19 Grade III GFRP bars were tested. Table 3 shows the mechanical properties of the GFRP bars used as per the manufacturer datasheets.

Table 1 Physical properties of the MST-BAR

<table>
<tr><th colspan="5">MST-Bar 60 GPa Bars</th></tr>
<tr><th>Description</th><th colspan="2">Code/Standard</th><th>Value</th><th>Unit</th></tr>
<tr><td>Avg. Bar Diameter</td><td colspan="2">CSA S807</td><td>15</td><td>mm</td></tr>
<tr><td>Fibre Content (by weight)</td><td colspan="2">-</td><td>> 80</td><td>%</td></tr>
<tr><td>Resin Type</td><td colspan="2">-</td><td>Vinyl Ester</td><td></td></tr>
<tr><td rowspan="2">Cross-sectional Area</td><td rowspan="2">CSA-S807</td><td>Nominal</td><td>199</td><td>mm^2</td></tr>
<tr><td>Effective incl. ribs</td><td>241</td><td>mm^2</td></tr>
<tr><td>Minimum Guaranteed Ultimate Tensile Strength</td><td colspan="2">ASTM D7205 / CSA S806</td><td>1000</td><td>MPa</td></tr>
<tr><td>Modulus of Elasticity</td><td colspan="2">ASTM D7205 / CSA S806</td><td>60</td><td>GPa</td></tr>
<tr><td>Linear Weight</td><td colspan="2">-</td><td>550</td><td>g/m</td></tr>
<tr><td>Minimum Bond Strength to Concrete</td><td colspan="2">-</td><td>20</td><td>MPa</td></tr>
</table>

2.1.2 Concrete Mixes

Two concrete mixes were used for the test slabs. Both mixes are produced by Lafarge Quebec and have a minimum compressive strength of 60 MPa. The first mix is the Type P17 RMXX60A5D17F and the second is Type P5 RMXX60A5DF5F with Masterfiber M100 fibres added to the mix. Two test slabs were poured from a ready-mix concrete truck, and qualified concrete finishers did the concrete finishing for the slabs, which were chemically cured using the Sealtight 1100 from W.R. Meadows. The mechanical properties of concrete of the two mixes are presented in the following table.

Table 2 Compressive Strength results of concrete mixes

Specified compressive strength at 28 days (MPa)	60
Maximum dimension of aggregate (mm)	14

Results			
Core number	Type P17	Type P17	Type P5
Age of concrete (days)	164	164	97
Average diameter (mm)	76.0	76.0	75.9
Capped Length (mm)	151.5	150.8	149.7
Type of capping	grinded	grinded	grinded
Length/Diameter (L/D)	1.99	1.98	1.97
Correction factor	1.00	1.00	1.00
Maximum Load (kN)	279.892	283.450	297.899
Compressive Strength corrected (MPa)	61.6	62.4	65.8

2.1.3 Chemical Anchoring Adhesive

The HILTI HIT-RE 500 V3 was used as an adhesive. The HILTI HIT-RE 500 V3 is an ultimate-performance injectable adhesive mortar that is approved for cracked and uncracked concrete in dry, submerged, water-filled, and wet conditions. It is ICC approved for rebar connections and heavy-duty anchoring against static, wind, and seismic loads. It can be used with threaded rods and rebar in temperatures ranging from -5 °C to 41 °C with a curing time of 168 hours to 4 hours, respectively, noting that a submerged or saturated concrete surface would double the curing time.

Table 3 Physical properties of the HILTI HIT-RE 500 V3 per manufacturer datasheet

HILTI HIT-RE 500 V3			
Description	Value	Unit	Test Standard
Bond Strength	11.7	MPa	ASTM C882-13A
Compressive Strength	82.7	MPa	ASTM D695-10
Compressive Modulus	2600	MPa	ASTM D695-10
Tensile Strength	49.3	MPa	ASTM D638-14
Elongation at break	1.1	%	ASTM D638-14
Heat Deflection	50	°C	ASTM D648-0
Absorption	0.18	%	ASTM D570-98
Linear Coefficient of Shrinkage on cure	0.008		ASTM D2566-86

2.2 Testing Method and Setup

2.2.1 Test Setup

The test setup is designed and built per the requirements of ASTM E3121/E3121M – 17 (ASTM E3121, 2017). Two different 2-inch loading plates are used for the confined and unconfined tests. A 60-ton hydraulic cylinder is used – the Enerpac RCH-603 Hydraulic Cylinder to apply the load. This cylinder is used due to its hole diameter (almost 2"). This allowed the installation of the cylinder through the cast-in-place pipe around the GFRP bars as it needs to be wide enough to be lifted and slipped down the anchors. The hydraulic cylinder has a stroke of 70 mm (3") to allow for in-situ adjustment and elongation of the bars.

As ASTM E3121/E3121M – 17 (ASTM E3121, 2017) has no recommendation for the preparation required for the GFRP rebars, the samples were prepared as per ASTM D7913 (ASTM, 2014). In other words, steel pipes were grouted on the free end of the GFRP bars. A hydraulic cylinder then pushes against the steel pipes at the top during the pullout test in the field. Figure 1 and Figure 2 show two test setups for confined and confined samples.

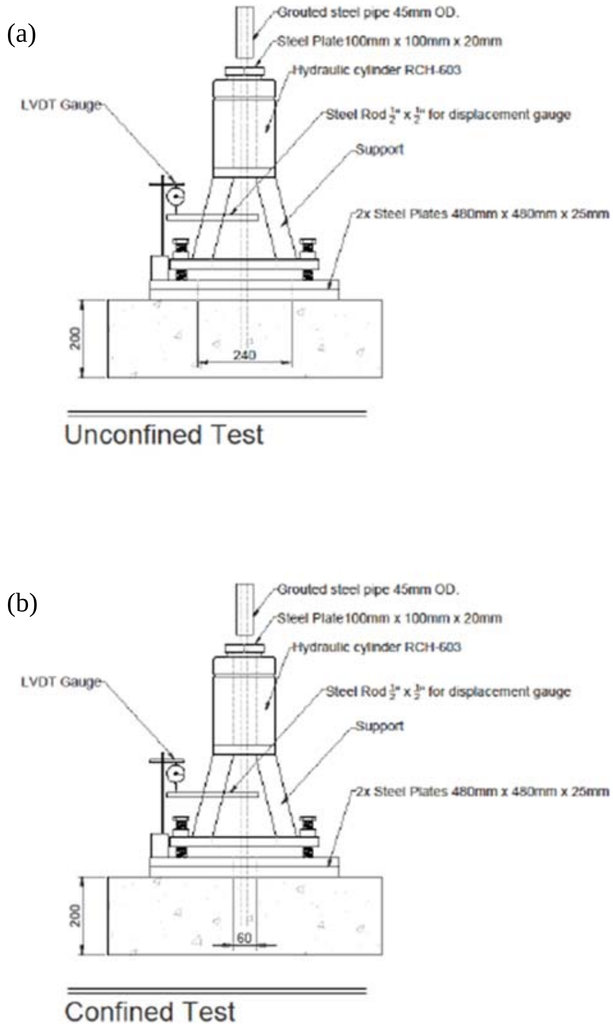


Figure 1 Testing setup for (a) Unconfined Pullout Test, and (b) Confined Pullout Test

(a) (b)

Figure 2 Test setup: (a) Unconfined; (b) Confined

2.2.2 Test Slab

Two unreinforced slabs measuring 4.0 x 4.0 x 0.2 m were poured to avoid the effect of confinement. Hence, the results obtained are conservative compared to the actual field conditions where these dowels will typically be anchored in a reinforced concrete element. Moreover, the preparation of the samples replicated usual field conditioning, including the method of drilled holes by carbide-tipped bits, cleaning of holes per the adhesive manufacturer requirements, moisture condition of the holes, and installation and curing procedure for the adhesive dowels.

2.2.3 Drilled Holes for Dowels and Layout

The drilling and cleaning of the holes were done following the supplier's requirements. The hole diameter was 25.4 mm and drilled with a carbide-tipped bit to simulate field conditions where drilling is typically done to avoid damaging rebar in existing decks. The effective embedment depth of the dowel did not exceed 125 mm.

2.2.4 Adhesive and Installation of Dowels

The application of adhesive and installation of dowels were made per the supplier's requirements. The dowels were installed in dry concrete. The concrete temperature at the time of application was greater than 0 degrees centigrade. Due to the length of GFRP bars, a formwork was installed around the bars during the curing stage to allow for perpendicular positing of the dowel with respect to the precast test slab. See schema below:

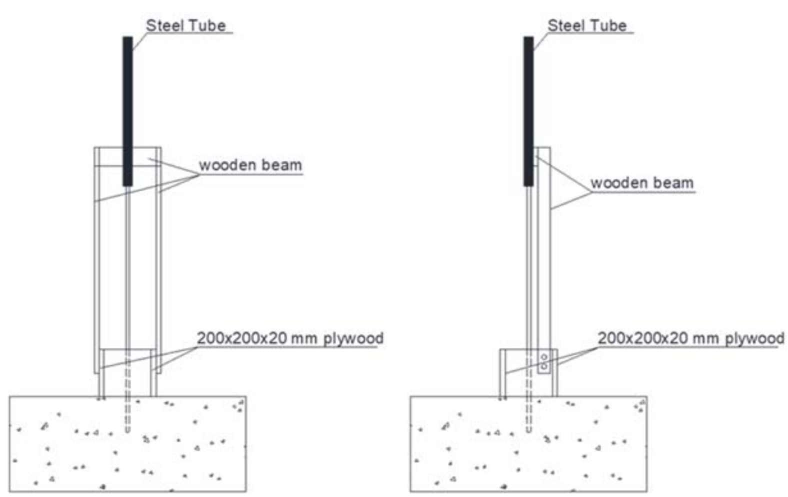


Figure 3 Formwork Layout per GFRP bar during Curing

3 Test Observations

In general, in-situ testing of post-installed GFRP anchors could have the following failure modes or their combination:

- Rupture of GFRP bar: this indicates that the bond between the GFRP and the adhesive and between the adhesive and concrete is higher than the bar's tension capacity. This failure mode was not reached on site, as it represents the highest failure load. However, two tests, one in normal concrete and one in fibre-reinforced concrete, were stopped when the loading reached close to the nominal tensile capacity of the bars, due to health and safety (H&S) concerns, and not limitations of the equipment or sample bars.
- Pullout of GFRP and the adhesive from concrete (adhesive-concrete pullout): this indicates that the bond between the adhesive and concrete controls the design.
- Pullout of the GFRP from the adhesive (GFRP-adhesive pullout): this indicates that the bond between the GFRP bars and the adhesive controls the design.
- Concrete cone failure.
- Slab shear failure: this indicates that the splitting forces developed because of force transfer from rebar to adhesive and/or from adhesive to concrete was larger than the splitting strength of concrete. Providing larger spacing between the samples and edge of the slab or using a reinforced concrete slab would have prevented this type of failure.

3.1 Observed Failure Modes

The following figures show the failure modes of the tested MST-BAR with HILTI HIT-RE 500 adhesive:

Figure 4 Example failure mode of slab shear failure (unconfined normal concrete sample 2)

Figure 5 Pullout of GFRP from adhesive and concrete cone failure in unconfined normal concrete (sample 3)

Figure 6 Pullout of GFRP from adhesive and concrete cone failure in unconfined normal concrete (sample 4)

Figure 7 Shear failure in confined fibre-reinfroced concrete (sample 2)

Figure 8 Test stopped before failure for H&S concerns in confined fibre-reinforced concrete (sample 3)

Figure 9 Pullout of GFRP from the adhesive in confined fibre-reinforced concrete (sample 5)

Figure 10 Pullout of GFRP from adhesive and concrete cone failure with the unconfined fibre-reinforced concrete (sample 2)

Figure 11 Pullout of GFRP from adhesive and concrete cone failure with the unconfined fibre-reinforced concrete (sample 3)

Figure 12 Concrete cone failure in unconfined fibre-reinforced concrete (sample 4)

Figure 13 Concrete cone failure in unconfined fibre-reinforced concrete (sample 5)

4 Summary of Results

A total of 15 in-situ pullout tests were performed to evaluate the anchorage capacity of MST-BAR with HILRI RE 500. Out of 15 samples, 5 samples were post-installed in FRC concrete, and the other 10 were in both normal concrete.

The tables below list the failure load, calculated failure stress, and the observed failure mode of all samples. The anchorage stress is calculated based on a nominal reinforcement area of 199 mm^2, CSA S807-19 (Canadian Standards Association, 2019). The average, standard deviation, and coefficient of variation of each group are also listed in the tables.

Table 4 Summary of unconfined tests results of MST-BAR with the HILTI HIT-RE 500 V3 adhesive in fibre-reinforced concrete (FRC)

Sample	Failure Load kN	Failure Stress MPa	Failure Mode*
Sample 1	144.4	726	GFRP-adhesive pullout and concrete cone failure
Sample 2	164.6	827	GFRP-adhesive pullout and concrete cone failure
Sample 3	176.2	885	Concrete cone failure
Sample 4	179.1	900	Concrete cone failure
Sample 5	184.8	929	GFRP-adhesive pullout and concrete cone failure
Average	169.8	853	
Standard Deviation	16.0	80	
Coefficient of Variation (%)	9	9	

Table 5 Summary of confined tests results of MST-BAR with the HILTI HIT-RE 500 V3 adhesive in fibre-reinforced concrete (FRC)

Sample	Failure Load kN	Failure Stress MPa	Failure Mode*
Sample 1	167.5	842	GFRP-adhesive pullout and concrete cone failure
Sample 2	173.3	871	Shear Failure
Sample 3	190.6	958	Test Stopped due to H&S Concerns
Sample 4	150.2	755	GFRP-adhesive pullout and concrete cone failure
Sample 5	150.2	755	GFRP-Adhesive Pullout
Average	166.4	836	
Standard Deviation	17.0	86	
Coefficient of Variation (%)	10	10	

Table 6 Summary of unconfined tests results of MST-BAR with the HILTI HIT-RE 500 V3 adhesive in normal concrete

Sample	Failure Load kN	Failure Stress MPa	Failure Mode*
Sample 1	173.3	871	GFRP-Adhesive Pullout and Cone Failure
Sample 2	141.6	711	Shear Failure
Sample 3	153.1	769	Concrete Cone Failure
Sample 4	153.1	769	GFRP-Adhesive Pullout
Sample 5	196.4	987	Test Stopped due to H&S Concerns
Average	163.5	822	
Standard Deviation	21.6	109	
Coefficient of Variation (%)	13	13	

5 Conclusions

This in-situ testing effort evaluates the pullout failure loads of MST-Bar GFRP rebars with HILTI HIT-RE 500 V3 in an oversize hole. The hole had a diameter of 25.4 mm, and the bars were all #5 (15 mm) with an embedment length of 125 mm. From the results, it can be concluded that the oversize hole was not much of an issue, and all samples behaved consistently. The MST-Bar GFRP rebar with the HILTI HIT-RE 500 V3 adhesive showed the average pullout capacity of 169.8 kN, 166.4 kN, and 163.5 kN for unconfined fibre-reinforced concrete, confined fibre-reinforced concrete, and unconfined normal concrete, respectively. The average anchorage stress, calculated based on the nominal reinforcement area of 199 mm^2, CSA S807-19 (Canadian

Standards Association, 2019), was 853 MPa, 836 MPa, and 822 MPa for unconfined fibre-reinforced concrete, confined fibre-reinforced concrete, and unconfined normal concrete, respectively. Based on experimental results, it can also be deduced that the concrete mix, whether normal concrete or fibre-reinforced concrete, has a minor effect on the failure loads, which might be attributed to the fact that both concrete mixtures had similar compressive strength.

Acknowledgments

We would like to acknowledge the in-kind support of Signature sur le Saint-Laurent Consortium for performing the tests and sharing the data and test results with the Centre for Structural Safety and Resilience at Concordia University. This report is part of an M.Eng. project report done by the second author under the supervision of the first and third authors at Concordia University.

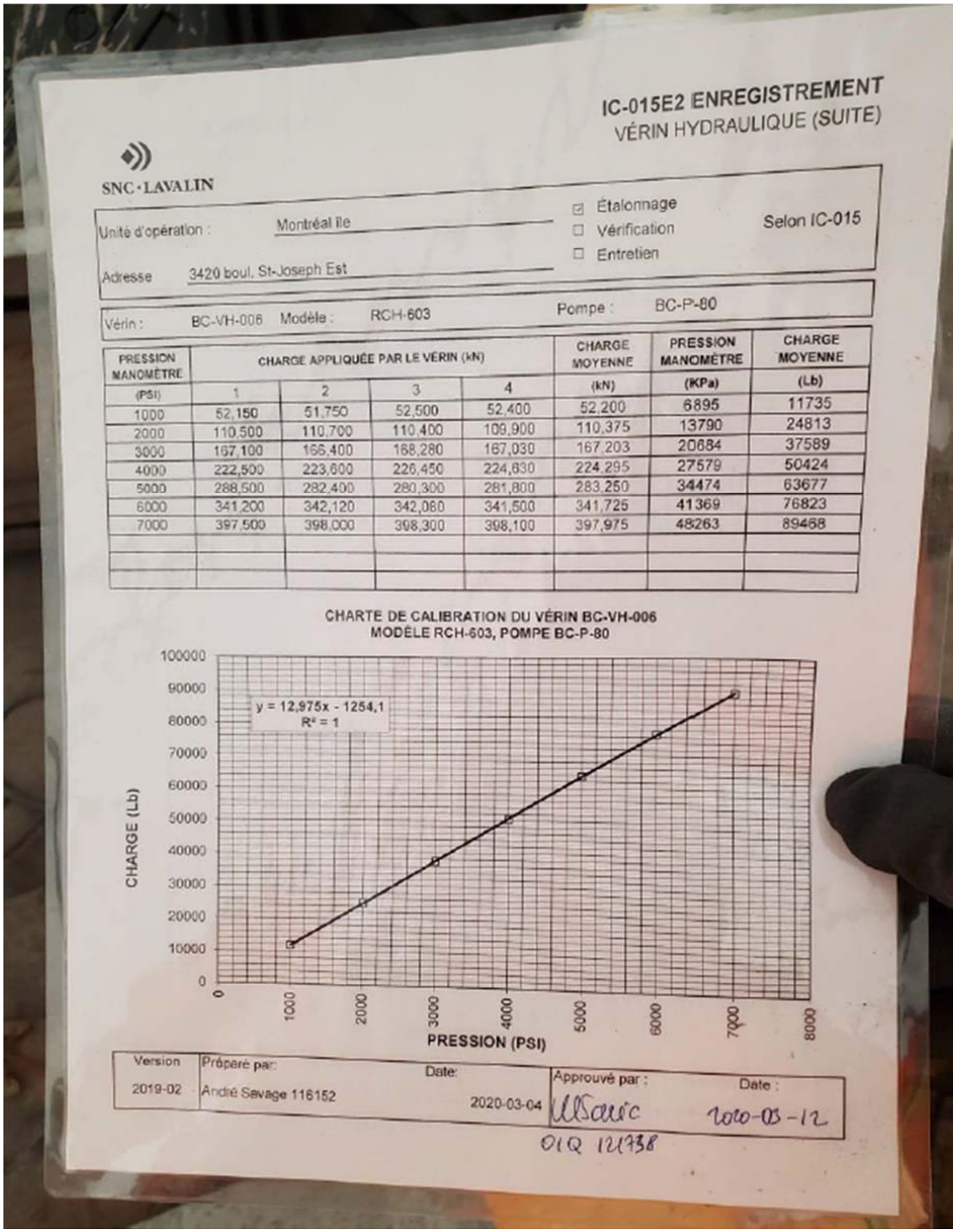
6 References

ASTM. (2014). ASTM D7913/D7913M-14: Standard test method for bond strength of fiber-reinforced polymer matrix composite bars to concrete by pullout testing. *ASTM Standards*, 1–9. https://doi.org/10.1520/D7913

ASTM E3121. (2017). Standard Test Methods for Field Testing of Anchors in Concrete or Masonry. *ASTM Standards, December 2017*, 1–7. https://doi.org/10.1520/E3121

Canadian Standards Association. (2019). *Specification for fibre-reinforced polymers (CSA S807-19)*. Canadian Standards Association.

Appendix 1: Certification and Load Calibration curve of the Hydraulic Cylinder



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IC-015E2 ENREGISTREMENT
VÉRIN HYDRAULIQUE (SUITE)

Unité d'opération : Montréal île

Adresse 3420 boul. St-Joseph Est

☑ Étalonnage
☐ Vérification
☐ Entretien

Selon IC-015

Vérin : BC-VH-006 Modèle : RCH-603 Pompe : BC-P-80

PRESSION MANOMÈTRE	CHARGE APPLIQUÉE PAR LE VÉRIN (kN)				CHARGE MOYENNE	PRESSION MANOMÈTRE	CHARGE MOYENNE
(PSI)	1	2	3	4	(kN)	(KPa)	(Lb)
1000	52,150	51,750	52,500	52,400	52,200	6895	11735
2000	110,500	110,700	110,400	109,900	110,375	13790	24813
3000	167,100	166,400	168,280	167,030	167,203	20684	37589
4000	222,500	223,600	226,450	224,630	224,295	27579	50424
5000	288,500	282,400	280,300	281,800	283,250	34474	63677
6000	341,200	342,120	342,080	341,500	341,725	41369	76823
7000	397,500	398,000	398,300	398,100	397,975	48263	89468

CHARTE DE CALIBRATION DU VÉRIN BC-VH-006
MODÈLE RCH-603, POMPE BC-P-80

Version	Préparé par:	Date:	Approuvé par :	Date :
2019-02	André Savage 116152	2020-03-04	[signature]	2020-03-12

01Q 121738

SNC·LAVALIN

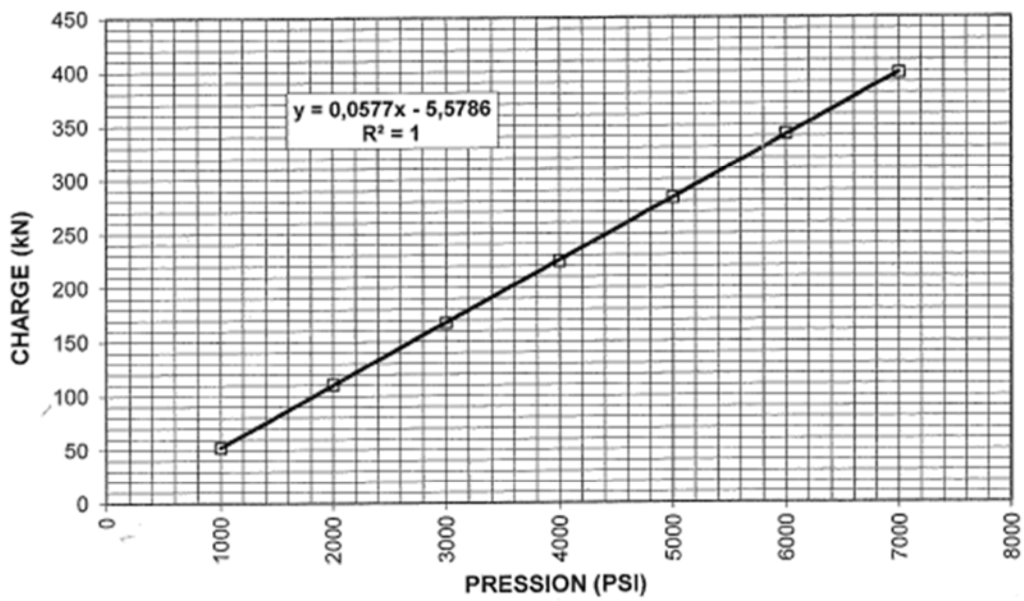
IC-015E2 ENREGISTREMENT
VÉRIN HYDRAULIQUE

Unité d'opération :	Montréal île	☑ Étalonnage ☐ Vérification ☐ Entretien	Selon IC-015
Adresse	3420 boul. St-Joseph Est		

Vérin : BC-VH-006 Modèle : RCH-603 Pompe : BC-P-80

PRESSION MANOMÈTRE	CHARGE APPLIQUÉE PAR LE VÉRIN (kN)				CHARGE MOYENNE	PRESSION MANOMÈTRE	CHARGE MOYENNE
(PSI)	1	2	3	4	(kN)	(KPa)	(Lb)
1000	52,150	51,750	52,500	52,400	52,200	6895	11735
2000	110,500	110,700	110,400	109,900	110,375	13790	24813
3000	167,100	166,400	168,280	167,030	167,203	20684	37589
4000	222,500	223,600	226,450	224,630	224,295	27579	50424
5000	288,500	282,400	280,300	281,800	283,250	34474	63677
6000	341,200	342,120	342,080	341,500	341,725	41369	76823
7000	397,500	398,000	398,300	398,100	397,975	48263	89468

CHARTE DE CALIBRATION DU VÉRIN BC-VH-006
MODÈLE RCH-603, POMPE BC-P-80



Version	Préparé par :	Date :	Approuvé par :	Date :
2019-02	André Savage 116152	2020-03-04	U.Isaurc	2020-03-12

OIQ 121738

Appendix 2: Technical Datasheet for the Masterfiber M100

3	03 30 00	Cast-in-Place Concrete
	03 37 13	Shotcrete
	03 40 00	Precast Concrete
	03 70 00	Mass Concrete

MASTER®
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MasterFiber® M 100

Monofilament Microsynthetic Fiber

Description

MasterFiber M 100 product is a high-tensile strength, high modulus of elasticity, ultra-thin monofilament homopolymer polypropylene fiber designed to quickly distribute uniformly throughout the concrete matrix. At the engineered dosage level of 0.50 lb/yd³ (0.3 kg/m³) MasterFiber M 100 product outperforms all other plastic shrinkage fiber reinforcements at their typical dosage of 1.0 lb/yd³ (0.6 kg/m³).

Applications

Recommended for use in:

- Residential slabs-on-ground
- Commercial slabs-on-ground
- Stucco
- Dry-packaged cement based products
- Precast products
- Pools and pool decks
- Water tanks
- Shotcrete

Features

- 225 million 0.75 in. (19 mm) fibers in one pound (0.45 kg) of product
- Uniform distribution throughout the concrete matrix
- Excellent finishability

Benefits

- Excellent reduction in plastic shrinkage cracking
- Transforms macro-cracks into micro-cracks
- Measurably reduces plastic settlement
- Measurably reduces the concrete permeability, thus increasing the durability and service life of the concrete
- Performs as an excellent companion in blends with macrosynthetic fibers and steel fibers

Performance Characteristics

Physical Properties

Specific Gravity	0.91
Melting Point	320 °F (160 °C)
Ignition Point	1,094 °F (590 °C)
Absorption	Nil
Alkali Resistance	Excellent
Tensile Strength	70 ksi (480 MPa)
Modulus of Elasticity	1,230 ksi (8.48 GPa)
Available Lengths	0.5 in. (13 mm) and 0.75 in. (19 mm)
Equivalent Diameter	0.00047 in. (12 microns)
Denier	1 dpf

A brand of MBCC GROUP

Guidelines for Use

Dosage: The recommended dosage of MasterFiber M 100 product is 0.50 lb/yd³ (0.3 kg/m³).

Mixing: Typically no modifications to the mixture proportions are required when the product is used at the engineered dosage of 0.50 lb/yd³ (0.3 kg/m³). MasterFiber M 100 product fibers can be introduced into the mixing system at any time except when the cement is being introduced. Mixing time will vary based on when the fibers are introduced to the mixer. The normal range is 3-5 minutes of mixing with the higher number preferred when the fibers are added after all of the standard ingredients have been introduced and mixed.

Engineering Specifications

MasterFiber M 100 product is a uniquely developed fiber to minimize plastic shrinkage cracking in concrete. With 112.5 million fibers in the engineered dosage of 0.50 lb/yd³ (0.3 kg/m³), MasterFiber M 100 product is capable of reducing plastic shrinkage cracking by approximately 85%. Conventional monofilament polypropylene fibers at 1.0 lb/yd³ (0.6 kg/m³) typically do not achieve 70% reduction in plastic shrinkage cracking.

MasterFiber M 100 product meets the requirements of ASTM D 7508/D 7508M, ASTM C 1116/C 1116M, Section 4.1.3, Type III and Note 2 as well as ICC ES AC32, Section 3.1.1 when used at the engineered dosage of 0.50 lb/yd³ (0.3 kg/m³).

Product Notes

MasterFiber M 100 product is not a replacement for structural steel reinforcement and therefore, should not be used to replace any of the load-carrying steel reinforcement in a concrete element.

Packaging

MasterFiber M 100 product is packaged in pre-weighed 0.50 lb (0.23 kg) and 2.5 lb (1.13 kg) degradable bags to ensure optimum dosing and homogeneous distribution of the product.

Related Documents

Safety Data Sheets: MasterFiber M 100 product

Additional Information

For additional information on MasterFiber M 100 product, contact your local sales representative.

Master Builders Solutions, a brand of MBCC Group, is a global leader of innovative chemistry systems and formulations for construction, maintenance, repair and restoration of structures. The Admixture Systems business provides advanced products, solutions and expertise that improve durability, water resistance, energy efficiency, safety, sustainability and aesthetics of concrete structures, above and below ground, helping customers to achieve reduced operating costs, improved efficiency and enhanced finished products.

Utilizing worldwide resources, the Master Builders Solutions community of experts are passionate about providing solutions to challenges within all stages of construction, as well as the life cycle of a structure. At Master Builders Solutions we create sustainable solutions for construction around the globe.

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