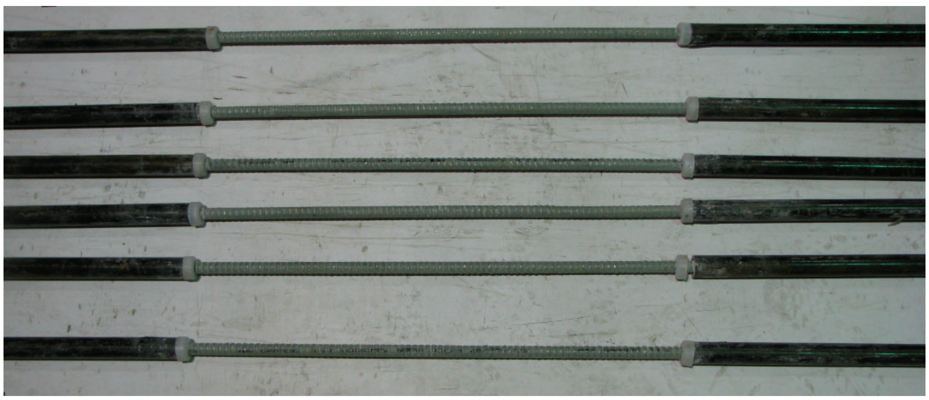
APPENDIX 8

UNIVERSITÉ DE SHERBROOKE

NSERC Research Chair in Innovative FRP Reinforcement for Concrete Infrastructure

Longitudinal Tensile Properties of MSTBAR GFRP Rebar of Size 15 mm (Lot1, Lot2, & Lot3) at Cold Temperature (-40°C)

Technical Report No 36



Prepared by:

Brahim Benmokrane, P. Eng., Ph.D.

NSERC Research Chair in Innovative FRP Reinforcement for Concrete Infrastructure
Canada Research Chair in Advanced Composite Materials for Civil Structures
Department of Civil Engineering
University of Sherbrooke
Sherbrooke, QC
Canada J1K 2R1
Phone: (819) 821-7758; Fax: (819) 821-7974
E-mail: Brahim.Benmokrane@USherbrooke.ca

Submitted to:

Borna Hajimiragha
President
B&B FRP Manufacturing Inc.
T: (416)740-0377
E-mail: Borna.H@bandbfrp.com
Website:www.bandbfrp.com

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INTRODUCTION

This report presents the longitudinal tensile properties of MSTBAR GFRP bars manufactured by B&B FRP Manufacturing Inc. (Ontario, Canada) at cold temperature as part of the certification of the product as internal reinforcement for concrete structures according to CSA-S807-10. Twenty-Four (24) specimens of GFRP bars of size 15 mm of production lot No 1, No 2, and No 3 (8 specimens per production lot) were shipped to Professor Brahim Benmokrane, NSERC/ Industrial Research Chair in Innovative FRP Reinforcement for Concrete Infrastructures at the Department of Civil Engineering at the University of Sherbrooke for tensile testing. The GFRP bars are manufactured using highly resistant glass fibres embedded in a vinyl ester resin. The GFRP bars have a continuously profiled surface. The tests were conducted under the direction of Professor Brahim Benmokrane at the Department of Civil Engineering of University of Sherbrooke.

This report presents the tensile properties of the MSTBAR GFRP bars (15mm) at cold temperature of -40°C for each production lot (Lot1, Lot2, and Lot3) according to ASTM D618 and CSA-S806-12, Annex C, as specified in CSA S807-10.

TEST SPECIMENS

A total of 8 specimens per production lot were tested. The specimens were received with the anchorage tubes installed and ready for testing. The specimens were tested in tension at cold temperature of -40°C till failure and longitudinal tensile properties were determined.

TESTING METHOD

The GFRP specimens were tested in accordance to ASTM D618, CSA-S806-12, Annex C – *"Test Method for Tensile Properties of FRP Reinforcement",* and ASTM D7205 (reapproved 2011)), *"Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars".*

The test specimens were instrumented with one LVDT of 200 mm length to capture the specimen elongation during testing. The tests were carried out using the Baldwin testing machine in the structures laboratory of the Civil Engineering Department at the University of Sherbrooke. The load was increased until tensile failure occurred. The applied load and bar elongation were electronically recorded during the test using a computerized data acquisition system. Figure 1 shows the test setup and a specimen during testing. During the test, the GFRP bars were maintained at cold temperature of -40°C according to ASTM D618. Through this test the ultimate tensile strength (f_u) and tensile modulus (E_L) of GFRP bars are determined. Mode of failure of the tested specimens at cold temperature are shown in figures 2 and 3.

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CALCULATION

The tensile strength, f_u, of GFRP bars was calculated according to the following equation:

$$f_u = \frac{F_u}{A} \tag{1}$$

where:
f_u = Tensile strength (MPa);
F_u = Tensile capacity (N); and
A = Cross-sectional area of the test bar (mm^2).

The tensile modulus of elasticity, E_L, was calculated from the difference between the load (stress)-strain curve values at 25 and 50% of the tensile capacity according to the following equation:

$$E_L = \frac{F_1 - F_2}{(\varepsilon_1 - \varepsilon_2)A} \tag{2}$$

where:
E_L = Longitudinal modulus of elasticity (MPa);
A = Cross-sectional area of the test bar (mm^2);
F_1 and ε_1 = Load and corresponding strain, respectively, at approximately 50% of the ultimate tensile capacity; and
F_2 and ε_2 = Load and corresponding strain, respectively, at approximately 25% of the ultimate tensile capacity, (N and dimensionless, respectively).

The nominal cross-sectional area provided by CAN/CSA S807-10 (2010) was used to determine the tensile properties: 199 mm^2 for GFRP bar having a designated diameter of 15 mm.

RESULTS

Table 1 present the longitudinal tensile properties of the GFRP bars for Lot1, Lot2, and Lot3 tested at room temperature, while Table 2 shows the longitudinal tensile properties of the GFRP bars for Lot1, Lot2, and Lot3 tested at cold temperature of -40°C. It can be seen that the tensile properties of the GFRP bars tested at cold temperature are little bit higher than those of GFRP bars tested at ambient temperature.

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(*Data from technical report No 6, dated Sep 15 2015 Report No13*)

Table 1: Longitudinal Tensile properties of MSTBAR GFRP Bars of 15 mm-Diameter (Area =199 mm^2) (Lot 1) at Room Temperature

Specimen No.	Ultimate Load (kN)	Ultimate Stress (MPa)	Tensile Modulus (GPa)	Ultimate Strain (%)
1	221	1111	69.9	1.59
2	221	1111	69.5	1.60
3	217	1090	69.6	1.57
4	214	1075	71.0	1.51
5	210	1055	70.6	1.49
6	207	1040	70.9	1.47
7	209	1050	70.7	1.48
8	216	1085	68.9	1.58
Average	**214**	**1077**	**70.1**	**1.54**
SD	**5**	**27**	**0.8**	**0.07**
COV (%)	**2**	**3**	**1**	**3**

Table 2: Longitudinal Tensile Properties of MSTBAR GFRP Bars of 15 mm-Diameter (Area =199 mm^2) (Lot 2) at Room Temperature

Specimen	Ultimate Load (kN)	Ultimate Stress (MPa)	Tensile Modulus (GPa)	Ultimate Strain (%)
1	211	1060	70.0	1.51
2	207	1040	70.3	1.48
3	220	1106	70.7	1.56
4	221	1111	71.6	1.55
5	219	1101	70.2	1.57
6	218	1095	70,7	1.55
7	213	1070	71.3	1.50
8	216	1085	69.7	1.56
Average	**216**	**1084**	**70.6**	**1.53**
SD	**5**	**25**	**0.6**	**0.05**
COV (%)	**2**	**2**	**1**	**2**

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Table 3: Longitudinal Tensile Properties of MSTBAR GFRP Bars of 15 mm-Diameter (Area =199 mm^2) (Lot 3) at Room Temperature

Specimen	**Ultimate Load (kN)**	**Ultimate Stress (MPa)**	**Tensile Modulus (GPa)**	**Ultimate Strain (%)**
1	214	1075	71.0	1.51
2	217	1090	70.2	1.55
3	214	1075	70.3	1.53
4	215	1080	70.5	1.53
5	209	1050	69.9	1.50
6	211	1060	70,2	1.51
7	203	1020	70.2	1.45
8	215	1080	69.6	1.55
Average	**212**	**1066**	**70.2**	1.52
SD	**4**	**22**	**0.4**	**0.05**
COV (%)	**2**	**2**	**1**	**2**

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Table 4: Tensile properties of MST-BAR GFRP bars size No. 5 - (Area =199 mm²) – at cold temperature (-40ºC). ***Tested under Cold Temperature of -40°C.***

Specimen	Lot #	Ultimate Load (kN)	Ultimate Stress (MPa)	Tensile Modulus (GPa)	Ultimate Strain (%)
1	#1	217	1090	68.3	1.6
2		235	1181	69.8	1.7
3		246	1236	69.4	1.8
4		231	1161	69.4	1.7
5		202	1015	68.5	1.5
6		238	1196	69.4	1.7
7		240	1206	69.6	1.7
8		224	1126	68.4	1.6
Average		**229**	**1151**	**69.1**	**1.7**
SD		**14.3**	**71.8**	**0.6**	**0.1**
COV (%)		**6.2**	**6.2**	**0.9**	**5.6**
1	#2	235	1181	68.9	235
2		235	1181	68.9	235
3		238	1196	69.3	238
4		235	1181	69.5	235
5		218	1095	69.5	218
6		214	1073	68.6	214
7		244	1226	69.2	244
8		237	1191	69.1	237
Average		**232**	**1166**	**69.1**	**232**
SD		**10.5**	**52.7**	**0.3**	**10.5**
COV (%)		**4.5**	**4.5**	**0.5**	**4.5**
1	#3	232	1166	69.3	1.7
2		230	1156	69.0	1.7
3		228	1146	69.3	1.7
4		245	1230	69.3	1.8
5		222	1116	70.4	1.6
6		235	1181	68.4	1.7
7		237	1191	68.9	1.7
8		230	1156	68.8	1.7
Average		**232**	**1168**	**69.1**	**1.7**
SD		**6.8**	**34.0**	**0.6**	**0.1**
COV (%)		**2.9**	**2.9**	**0.8**	**3.4**

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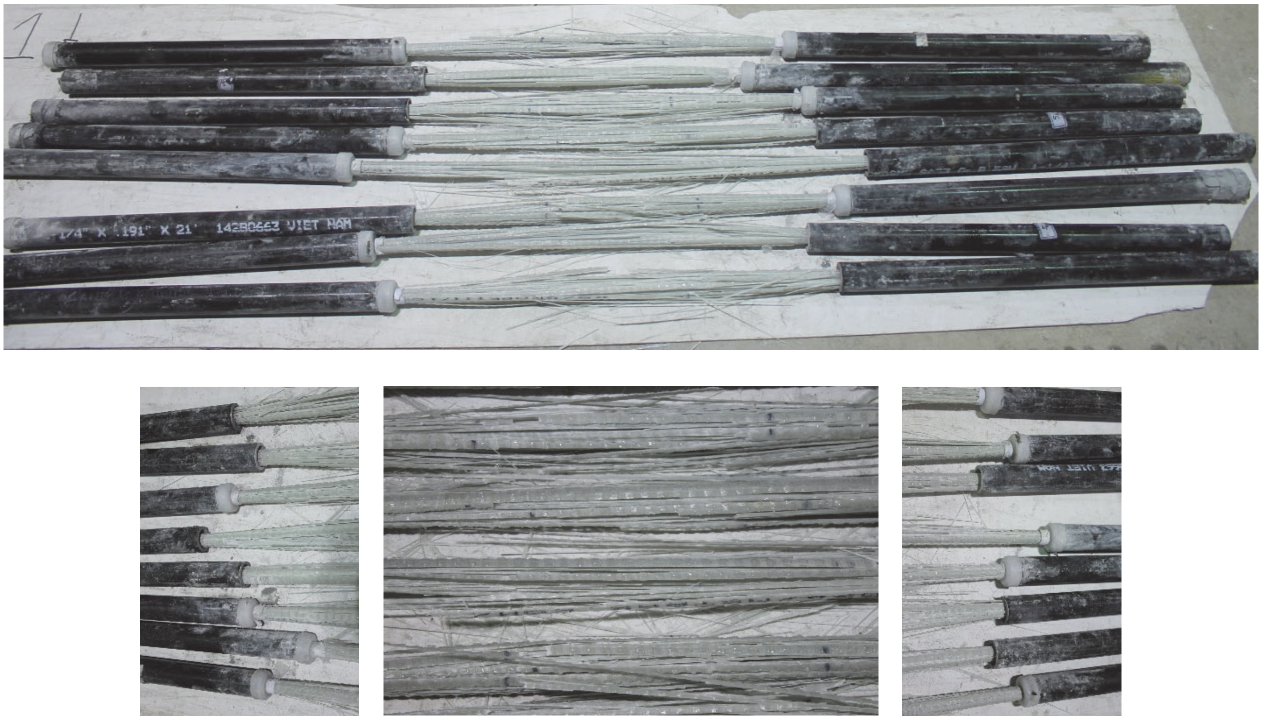
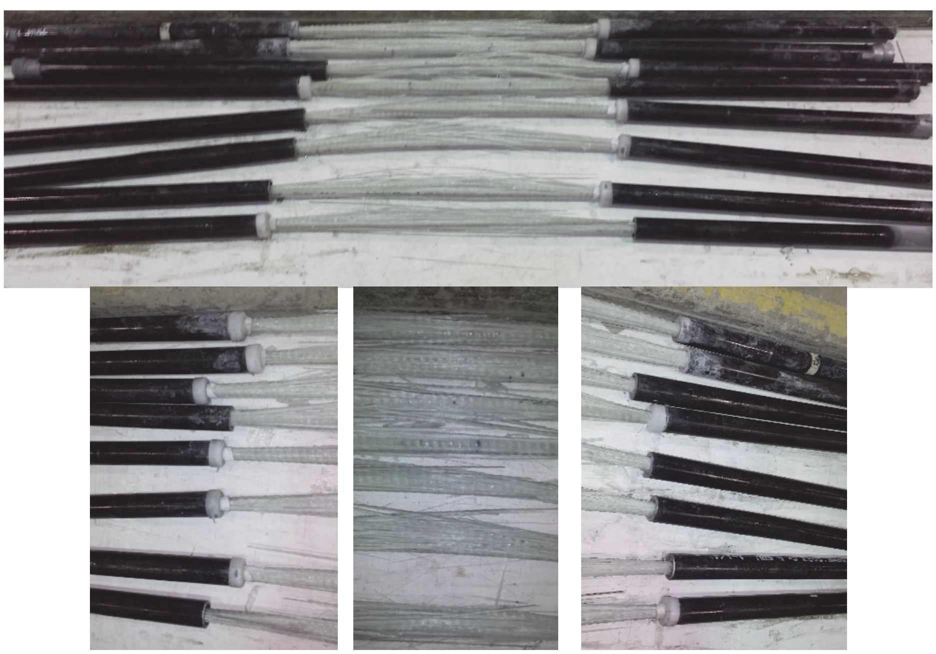
Photos of conditioned bars (Lot #1):



Photos of conditioned bars (Lot #2):



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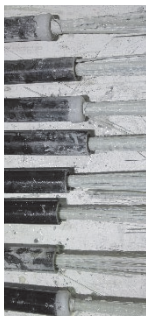
Photos of conditioned bars (Lot #3):



Strength and modulus retention

Table 2 present the strength and modulus retention of the MST-BAR GFRP bars #5 due to the conditioning in cold temperature of -40ºC

Table 2: Strength and modulus retention of the conditioned specimens

	Lot #	Ultimate Load (kN)	Tensile Modulus (GPa)	Strength retention (%)	Modulus retention (%)
Reference specimen	#1	214	69.0	-	-
	#2	216	69.5	-	-
	#3	213	69.2	-	-
Conditioned specimen during 90 days	#1	229	69.1	**107**	**100**
	#2	232	69.1	**108**	**99.5**
	#3	232	69.2	**110**	**100**

Concluded Remarks:

The average strength retention of the three different lots of MSTBAR GFRP bars size No. 5 (Lot #1, Lot #2, and Lot #3) is 108%, while the average modulus retention is 100%. The tested MSTBAR GFRP bars fulfill the requirement of the CSA S907-10 regarding the tensile properties at cold temperature. The requirement of the CSA S807 is as follow: «As compared to properties at room temperature, the loss of properties at specified low temperatures shall be less than 5%».

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REFERENCES

1. ASTM D7205 (Reapproved 2011) Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars, ASTM D7205 (reapproved 2011).
2. CAN/CSA-S806-12, 2012, "Design and Construction of Building Components with Fibre Reinforced Polymers," Canadian Standards Association, Rexdale, Ontario, Canada.
3. CAN/CSA-S807-10, 2010, "Specification for Fibre-Reinforced Polymers," Canadian Standards Association, Rexdale, Ontario, Canada, 27 p.