NORPLEX MICARTA

Global Thermoset Composite Solutions

May 18, 2016

Cryogenic Test Data for NP500CR

Thank you for your interest in Norplex-Micarta's cryogenic materials, specifically our grade NP500CR. This product has gained wide acceptance in several demanding cryogenic applications where strength and thermal insulation are needed simultaneously. From pipe shoes, to tank supports, to dozens of specialty applications, NP500CR has been successfully deployed – in some cases for decades.

As the demands for cryogenic applications has grown, we have been consistently asked for test data at cryogenic temperatures. To support the growth of the cryogenic applications, Norplex-Micarta invested in independent lab testing of compressive strength ("perpendicular to the laminations", "flatwise", or "Z" orientation) and in-plane shear. Details of these tests follow for your reference.

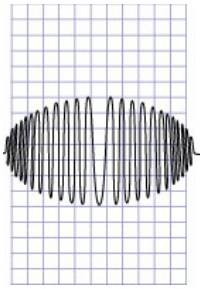
Additionally, NIST publishes thermal conductivity and thermal expansion values for NP500CR. That data can be found at: https://trc.nist.gov/cryogenics/materials/G-10%20CR%20Fiberglass%20Epoxy/G10CRFiberglassEpoxy_rev.htm

Norplex-Micarta presents this data under our standard terms and conditions which can be found on our website at: http://www.norplex-micarta.com/Portals/0/documents/terms_conditions/terms_and_conditions_of_sale.pdf

While the tests were performed by third parties under ASTM or other standard laboratory methods and conditions which are believed to be reliable, tests of individual lots of material will yield different results. *Users are reminded to independently and appropriately verify the suitability of NP500CR, or any other Norplex-Micarta material, for their intended application. Furthermore, these values are for reference only and should not be considered specification values.*

Again, thank you for your interest in Norplex-Micarta and NP500CR. We welcome the opportunity to discuss your need for cryogenic or other composite materials in more detail to support your design and engineering process.
Sincerely,

Dustin D. Davis
Director of Technology and Business Development



Final Report Rev1

for

NORPLEX-MICARTA

MECHANICAL MEASUREMENTS OF NP500CR SPECIMENS

May 4, 2016

Dustin Davis
TEL: 317-498-0149

NORPLEX-MICARTA
665 Lybrand Street
Postville, IA 52162

PURCHASE ORDER NUMBER 28307

TESTING SERVICES PROVIDED BY

Precision Measurements and Instruments Corporation
3665 SW Deschutes Street
Corvallis, OR 97333 USA

TEL: 541-753-0607
FAX: 541-753-0610
EMAIL: info@pmiclab.com

MECHANICAL MEASUREMENTS OF NP500CR SPECIMENS

WORK CONDUCTED FOR NORPLEX-MICARTA
PURCHASE ORDER NUMBER 28307

May 4, 2016

Precision Measurements and Instruments Corporation determined the shear strength of NP500CR test specimens by ASTM D3846. Measurements were made with an MTS 5000lb tensile test machine. Results are presented in Table 1. A brief description of the test procedure, data analysis and comments on the results follow.

Specimen Description

Norplex-Micarta provided the following specimens:

# of Specimens	Description	Length	Width	Thickness
34	NP500CR	79.6mm	12.7mm	6.35mm

The specimens were measured in the length direction.

Test Procedure

♦ Specimen Check-In

The specimens were received February 29, 2016, via Federal Express Ground. The specimens were inspected for damage. No specimen damage was observed.

Figure 1. Specimens as-received.

♦ Specimen Preparation

Specimens were tested as received.

♦ Measurements

An MTS 5000lb capacity mechanical test machine equipped with a 5000 pound load cell was used. The specimens were placed in a specimen loading jig designed for ASTM D695 (referenced by ASTM D3846) and loaded with a constant upper crosshead speed of 1.7 mm per minute until failure. Specimens were equipped with a thermocouple on the surface of the gage region and brought to the target temperature inside a liquid-nitrogen-cooled environment box while measured. For the coldest temperature point, liquid nitrogen was sprayed directly on specimens.

The data were processed using MTS QTest software. The stress was calculated as *load Cell output/shear area*.

♦ Extra Information

- The 5000 pound load cell used was last verified on 6 Apr 2015 in situ by Advanced Calibration Technologies, who are also ISO 17025-certified.
- Atmospheric conditions in the lab were 22.5 ± 1° C, 31 ± 3% rh, and 1005 ± 5 hPa.

Test Results

All tested specimens exhibited the mode of failure predicted by the standard: shear along the central vertical plane to which the notches were machined. Shear strength of each tested specimen is displayed in **Table 1,** along with the specimen temperature at time of testing. Averages, standard deviations and dates of testing are provided as additional information per ASTM D3846.

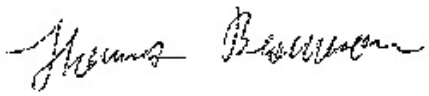
Table 1, Shear Strength of NP500CR specimens.

Nominal Temp (°C)	ID	Shear Strength (MPa)	Test Temp (°C)	Average and Std Dev. (MPa)	Date
	4	**94.7**	-50	Average	29-Mar-16
	9	**92.2**	-51	**93.1**	29-Mar-16
-50	16	**93.2**	-50		29-Mar-16
	15	**92.3**	-50	Std. Dev.	29-Mar-16
	28	**93.2**	-50	1.0	29-Mar-16
	1	**119.0**	-100	Average	29-Mar-16
	2	**123.3**	-99	**120.2**	29-Mar-16
-100	13	**116.6**	-100		29-Mar-16
	25	**125.4**	-100	Std. Dev.	29-Mar-16
	7	**116.8**	-100	4.0	29-Mar-16
	30	**138.2**	-149	Average	29-Mar-16
	34	**139.2**	-150	**135.3**	29-Mar-16
-150	24	**138.1**	-150		29-Mar-16
	17	**130.8**	-150	Std. Dev.	29-Mar-16
	3	**130.1**	-150	4.4	29-Mar-16
	22	**139.3**	-190	Average	30-Mar-16
	33	**143.4**	-190	**138.2**	30-Mar-16
-196	29	**136.8**	-190		30-Mar-16
	5	**137.7**	-190	Std. Dev.	30-Mar-16
	21	**133.8**	-190	3.5	30-Mar-16

Please contact our technical staff at (541) 753-0607 if you have any questions or require any additional information regarding these measurements.

Submitted by:

Don Schneider
Project Engineer

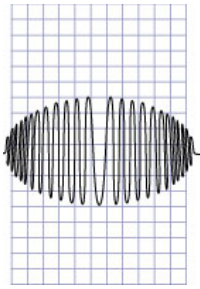


Thomas Brownson
Project Engineer

Darrell Oakes
Lab Manager

Precision Measurements and Instruments Corporation hereby claims that test results are obtained by techniques based on relevant ASTM standards, calibrations with NIST standard reference materials and/or published procedures. Thus, we accept no liability for test results beyond the cost of the contract rendered.

Quality Statement:
At PMIC, our policy is to consistently provide the maximum possible accuracy and reliability for materials properties test data, as requested by our customers. This level of quality is achieved through the adoption of a Quality Management System that reflects the competence of PMIC to existing customers, potential customers and independent auditing authorities.



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MECHANICAL MEASUREMENTS OF NP500CR SPECIMENS

WORK CONDUCTED FOR NORPLEX-MICARTA
PURCHASE ORDER NUMBER 28307

May 4, 2016

Precision Measurements and Instruments Corporation determined the compression strength of NP500CR test specimens by ASTM D695. Measurements were made with an MTS 5000lb tensile test machine. Results are presented in Table 1. A brief description of the test procedure, data analysis and comments on the results follow.

Specimen Description

Norplex-Micarta provided the following specimens:

# of Specimens	Description	Length	Width	Thickness
28	NP500CR	0.25"	0.25"	0.25"

Test Procedure

- Specimen Check-In

The specimens were received February 29, 2016, via Federal Express Ground. The specimens were inspected for damage. No specimen damage was observed.

Figure 1: Specimens as received

♦ Specimen Preparation

Test specimens were milled down to approximately 4.65 mm in the width and thickness directions and lightly sanded to improve flatness.

♦ Measurements

An MTS 5000lb capacity tensile tester equipped with a 5000 pound load cell was used. The specimens were placed in a sub-press designed for ASTM D695 and loaded with a constant upper crosshead speed of 0.05 inches per minute until failure. Specimens were equipped with thermocouples and kept at the target temperature inside a liquid-nitrogen-cooled environment box during testing, which can be seen in an exploded view in **Figure 2**. Atmospheric conditions in the lab were 22 ± 2º C, 35 ± 10% rh, and 1005 ± 15 hPa. All specimens were tested through-thickness (in the 'Z' direction) with respect to the fiber weave.

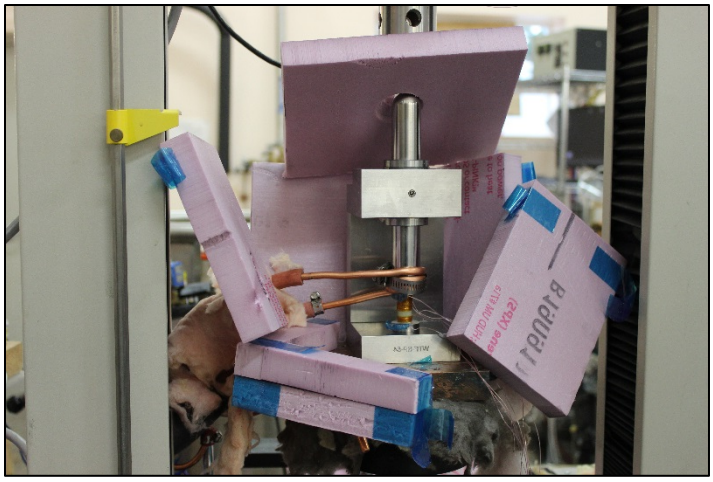


Figure 2: Test Set-up

The data were processed using MTS QTest software. The stress was calculated as *load Cell output/specimen area*.

Test Results

Specimens at all temperature points behaved similarly, exhibiting brittle failure along a plane roughly 45 degrees from vertical. Photographs of the failed specimens have been provided upon request, and can be seen in **Figures 3-6.**

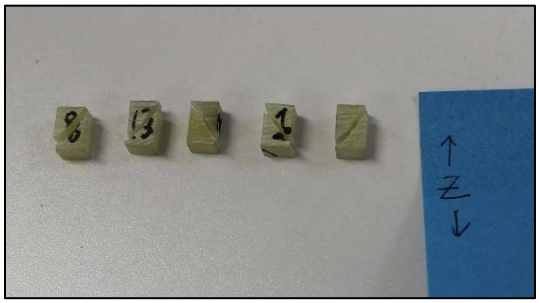


Figure 3: -50 C specimens post-test

Figure 4: -100 C specimens post-test

Figure 5: -150 C specimens post-test

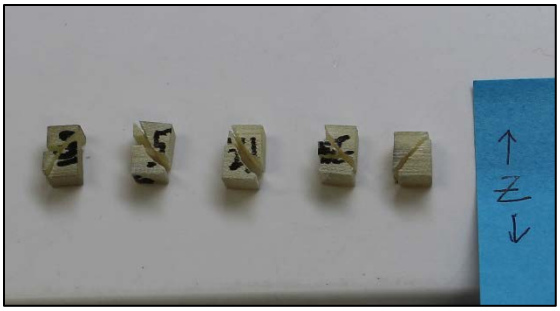


Figure 6: As cold as possible specimens post-test

Test data can be found in **Table 1,** which shows the ultimate strength for each specimen as well as an average and standard deviation of this value at each temperature. Specimen dimensions, test temperature, and dates of testing are provided as well, in accordance with ASTM D695.

Table 1, Compression Strength of NP500CR Specimens.

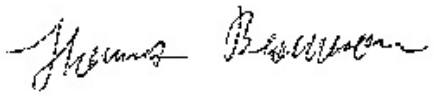
Nominal Temperature (ºC)	ID	Height (mm)	Width (mm)	Length (mm)	Test Temperature (ºC)	Ultimate Compressive Strength (MPa)	Average and Std. Dev.	Date of Test
-50	8	6.32	4.65	4.67	-49	**650.7**	Average	5-Apr-16
	13	6.32	4.63	4.66	-49	**653.1**	**656.6**	5-Apr-16
	12	6.32	4.53	4.60	-50	**647.5**		5-Apr-16
	1	6.33	4.68	4.63	-51	**680.0**	Std. Dev.	5-Apr-16
	4	6.32	4.64	4.66	-49	**651.8**	13.2	5-Apr-16
-100	3	6.33	4.68	4.68	-100	**768.0**	Average	5-Apr-16
	14	6.32	4.65	4.68	-100	**733.9**	**772.5**	5-Apr-16
	18	6.34	4.68	4.67	-96	**774.9**		5-Apr-16
	23	6.32	4.66	4.63	-97	**804.7**	Std. Dev.	6-Apr-16
	17	6.32	4.64	4.66	-97	**781.0**	25.6	6-Apr-16
-150	15	6.32	4.63	4.66	-147	**954.6**	Average	6-Apr-16
	7	6.35	4.63	4.66	-149	**858.4**	**908.5**	6-Apr-16
	25	6.32	4.64	4.66	-149	**922.9**		6-Apr-16
	27	6.34	4.70	4.65	-151	**895.3**	Std. Dev.	6-Apr-16
	11	6.35	4.58	4.65	-149	**911.5**	35.4	6-Apr-16
-196	16	6.35	4.61	4.50	-189	**902.2**	Average	4-Apr-16
	5	6.31	4.64	4.68	-194	**934.6**	**894.7**	5-Apr-16
	21	6.33	4.64	4.66	-194	**853.9**		5-Apr-16
	24	6.31	4.63	4.65	-194	**875.9**	Std. Dev.	5-Apr-16
	19	6.31	4.67	4.66	-194	**906.7**	30.9	5-Apr-16

Note: Test Method created on 30-Mar-2016

Please contact our technical staff at (541) 753-0607 if you have any questions or require any additional information regarding these measurements.

Submitted by:

Don Schneider
Project Engineer



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