ERDC/CRREL TR-14-10

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Engineering for Polar Operations, Logistics, and Research (EPOLAR)

Extreme Cold Testing of High Performance Fabric Materials

Gelbo Flex, Tensile Strength, and UV Exposure Test Results

Jason C. Weale and James H. Lever

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EP-ANT-13-46, “Models and Materials for SPoT Cargo and Fuel Sleds”

Abstract

The National Science Foundation's United States Antarctic Program (NSF-USAP) is constantly striving to introduce materials, methods, and equipment that will increase efficiency and reduce costs of their logistics and operations activities. Storage and transportation of bulk waste is a resource-intensive task for the USAP; and the introduction of high performance fabric containment and transport products, because they are cheaper, take up less volume when empty, and are lighter than the existing waste bins, could improve waste operations. We adapted standard test methods to represent Antarctic conditions to allow us to evaluate the behavior of high performance fabrics for the USAP.

We conducted cold temperature strength and flexibility tests on two commercially available off-the-shelf products. The fabrics were designed for the containment and transport of bulk-waste products in more temperate climates and required evaluation and testing to determine whether or not they might work for the USAP. The results from Gelbo flex tests (ASTM F392/F392M-11) on samples of both fabrics immediately removed one product from consideration. The successful product underwent tensile tests (ASTM D751) and UV exposure tests and was subsequently recommended for consideration. This report presents the American Society for Testing and Materials (ASTM) test methods (as adapted for extreme Antarctic conditions), the test results, the material behavior, and our recommendations.

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Preface

This study was conducted for National Science Foundation (NSF), Division of Polar Programs (PLR) under Engineering for Polar Operations, Logistics, and Research (EPOLAR) EP-ANT-13-46, “Models and Materials for SpoT Cargo and Fuel Sleds.” The technical monitor was George Blaisdell, Chief Program Manager for Antarctic Infrastructure and Logistics (AIL).

The work was performed by the Jason C. Weale and Dr. James H. Lever (Force Projection and Sustainment Branch, Dr. Edel Cortez, Chief), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL) Hanover, NH. Dr. Justin Berman was Chief of the Research and Engineering Division. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

The authors thank Glenn Durell of ERDC-CRREL for his technical expertise in using and adapting the MTS equipment to perform these tests. They also thank Jeffery Ryan of the Construction Engineering Research Laboratory (ERDC-CERL) for providing expertise and equipment to conduct the ultraviolet exposure tests. They sincerely thank George Blaisdell at NSF/PLR-AIL for his enthusiastic support.

The Commander ERDC is COL Jeffrey R. Eckstein, and the Director of ERDC is Dr. Jeffery P. Holland.

Unit Conversion Factors

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	0.0254	meters
pounds (force)	4.448222	newtons
pounds (mass)	0.45359237	kilograms

Acronyms and Abbreviations

AIL	Antarctic Infrastructure and Logistics
ASTM	American Society for Testing and Materials
CERL	Construction Engineering Research Laboratory
COTS	Commercial off-the-shelf
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
EPOLAR	Engineering for Polar Operations, Logistics, and Research
ERDC	U.S. Army Engineer Research and Development Center
ILPS	Inter-Link Packaging Solutions
NSF	National Science Foundation
PLR	Division of Polar Programs
SPoT	South Pole Overland Traverse
USAP	United States Antarctic Program
UV	Ultraviolet

1 Introduction

The National Science Foundation's (NSF) United States Antarctic Program (USAP) is constantly striving to introduce materials, methods, and equipment that will increase the efficiency of the their logistics and operations activities. These forward-looking implementation efforts improve science support by integrating modern developments into USAP. In this case, USAP was looking to improve the efficiency (while simultaneously driving down costs) of storing and transporting bulk waste both in Antarctica and in USAP's international logistics supply chain. USAP provided the U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL) with samples of two reinforced fabric materials for potential use in place of hard sided storage vessels. The bags are cheaper, take-up less volume when empty, and are lighter than the existing waste bins. Following American Society for Testing and Materials (ASTM) standards (as adapted for extreme Antarctic conditions), CRREL tested the fabric samples under severe cold and stress loads to observe their performance characteristics and to reduce the risk of field failure in high-latitude, extreme-cold, and high-elevation environs.

It should be noted that the materials tested for this project were from commercially available off-the-shelf products that were not specifically designed to withstand the polar environs, and the manufacturers made no claims to suggest they would. Identifying readily available materials that can perform in these conditions helps to keep USAP costs down and to ensure availability.

2 Service Conditions and Performance Requirements

The bulk-waste bags will be filled, lifted, and transported at temperatures to −40°C; and if stored outside at South Pole Station, they must survive storage at outdoor temperatures approaching −75°C (−55°C for outdoor winter storage at McMurdo Station). To help avoid catastrophic failure, the waste bags must behave elastically while being lifted and transported. High latitude, high elevation (about 10,000 ft at South Pole), and 24 hr summer daylight also have the potential to create significant ultraviolet (UV) exposure, which may impact material performance over time.

The USAP (through NSF) provided CRREL with samples of two commercial off-the-shelf (COTS) bulk-waste storage bag materials: one fabric sample from MonstaBag and two full-size bags from Inter-Link Packaging Solutions (ILPS). Though the manufacturers or their representatives made no performance claims, previous success with these products in the Arctic and the material data specifications for each fabric material suggested that they could possibly meet our service conditions and performance requirements.

In addition to meeting environmental and operating conditions, we would typically expect the waste bags to achieve a service life in excess of a single use. However, the logistics of managing waste transport out of Antarctica dictate a single-use life because it is not cost effective to collect and ship waste containers back to Antarctica. The USAP currently uses cardboard triwall containers, and these are the established baseline for any economic (not part of this study) and technical comparisons. Regardless, to minimize random and potentially catastrophic field failures, it is essential to field reliable products where we understand and can predict the replacement life cycles.

3 Laboratory Test Descriptions

All tests were performed in a temperature-controlled test chamber on a closed-loop, electro-hydraulic MTS Universal Testing Systems load frame. It has a 25,000 lb actuator with a 6 in. stroke. The insulated test chamber measures 20 in. wide, 36 in. deep, and 40 in. high. A cascade refrigeration system circulates cold air, using a thermocouple in the exiting air stream as feedback to control chamber temperature (± 0.1°C). The chamber is capable of reaching and maintaining −70°C.

The Gelbo flex test (ASTM F392/F392M-11 [ASTM 2011a]) is a standard test to evaluate fabric materials under conditions of severe flexing. These tests are not routinely conducted at temperatures relevant to Antarctic needs, and most manufacturers do not know how various combinations of woven fabric and bonded coatings will perform when flexed at −40°C. In addition, we planned to conduct Gelbo tests at −50°C and −60°C, provided the samples held-up to flexing at −40°C. These lower temperatures mimic the "shoulder" seasons (spring and fall) in the Antarctic and help to establish whether there is a material performance threshold at or near the required operating temperatures.

The Gelbo test imposed combined 440° rotation and 5.5 in. compression on the fabric specimens. The specimens were 3.5 in. wide with an approximate gage length of 6 in. The resulting flexing and folding was at least as severe as we expect will be imposed on the bulk-waste bags during handling and transport. We ran up to 2000 cycles (4-second duration per cycle) on the specimens and at 500-cycle intervals, assessed them for cracks, delamination, and other visual evidence of failure. We did not leak test the fabric samples because it is not expected that they will contain liquid waste.

We also conducted room temperature (23°C) and cold-soaked (−40°C) uniaxial tensile tests (ASTM D751 [ASTM 2011b]) on the materials that survived the Gelbo flex tests. After inserting 4 in. wide by 6 in. gage length samples into the MTS machine, a linear variable differential transformer that was incorporated in the actuator controlled the crosshead rate and measured total elongation. A 25,000 lb load cell mounted in line with the test fixture measured tensile force. Per the ASTM D751 specification

(ASTM 2011b), we held the crosshead rate constant at 12 in./min. We conducted two sets of tensile tests: one at room temperature (23°C) and a second at the previously defined field operating temperature of −40°C.

4 Gelbo Flex Tests

We conducted Gelbo flex tests on the ILPS and MonstaBag samples. The ILPS product consisted of a black protective shell (a lighter-weight external fabric layer designed for abrasion and UV protection) and a white structural liner (a heavyweight internal fabric material designed to carry the loads). Thus, we tested the ILPS materials individually (black protective shell and white structural liner) and as a system (layers back to back). Table 1 illustrates the planned test matrix for all material samples.

Table 1. Gelbo flex test plan matrix. The ILPS is a multi-layer system of an exterior black, lightweight, protective shell and an interior white, structural heavyweight liner. The MonstaBag product is a single-layer system with a bonded coating.

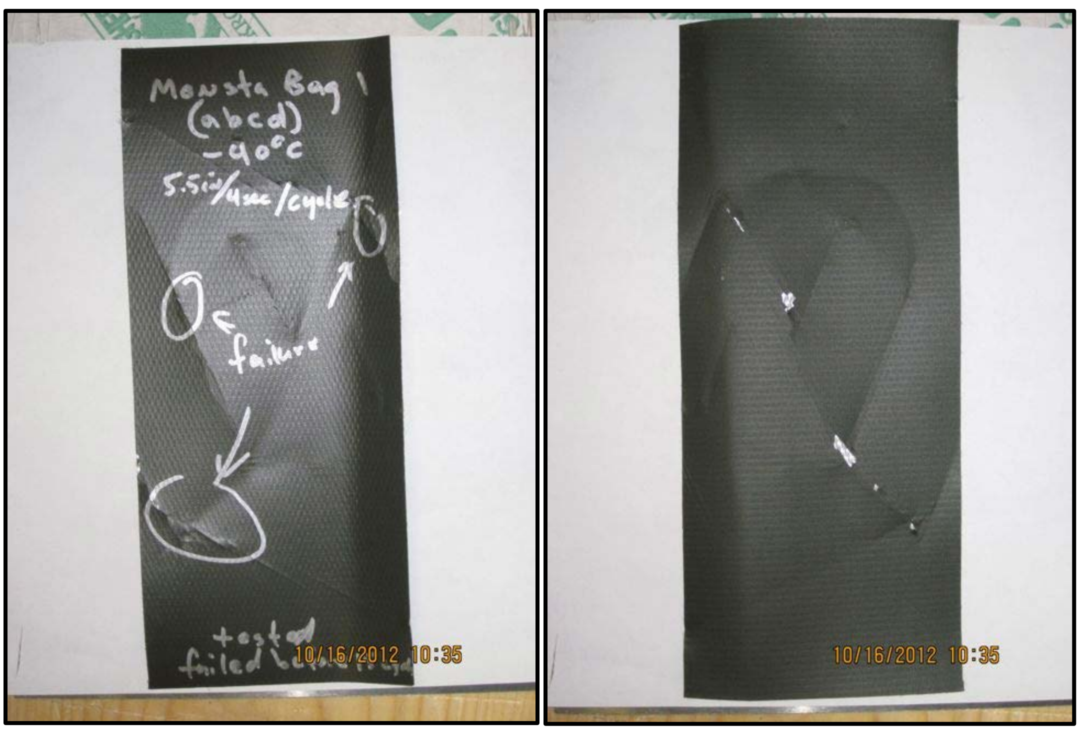
Sample Number	Temperature (°C)	Compression Rate (in./sec)	Twist Angle (degrees)	Total Cycles
ILPS Black Protective Shell 1	−40	2.75	440	2000
ILPS White Structural Liner 1	−40	2.75	440	2000
MonstaBag 1	−40	2.75	440	2000
ILPS Black Protective Shell 2	−50	2.75	440	2000
ILPS White Structural Liner 2	−50	2.75	440	2000
MonstaBag 2	−50	2.75	440	2000
ILPS Black Protective Shell 3	−60	2.75	440	2000
ILPS White Structural Liner 3	−60	2.75	440	2000
ILPS White Structural Liner + Black Protective Shell 4	−60	2.75	440	2000
MonstaBag 3	−60	2.75	440	2000

The Gelbo tests revealed significant differences in the two products. The ILPS black shell, white liner, and combined system survived (qualitatively) each test at successively lower temperatures (down to −60°C) with no apparent failures, degradations, or deformities of the shell, liner, or complete system (Figure 1).

Figure 1. ILPS fabric sample during Gelbo flex testing at −40°C. Note that the extreme twisting caused multiple folds but that these did not propagate cracks, tears, or deformities.

The MonstaBag product failed immediately during the initial tests at −40°C. In the first test, the product's bonded coating delaminated from the underlying woven fabric after fewer than 15 cycles (Figure 2).

Figure 2. MonstaBag front (left) and back (right) following Gelbo flex testing at −40°C. Note severe cracking on the front and bonded coating delamination (white areas) on the back that reveal woven fabric underneath.



In a repeat test at −40°C, the MonstaBag's bonded coating shattered away (visually and audibly) from the woven fabric on the initial compressivetwist (video of this test is available). These results eliminated the MonstaBag as a potential bulk-waste container solution; and we did not conduct any further Gelbo, tensile, or UV exposure tests on the product. Table 2 presents results for all of the Gelbo flex tests.

Table 2. Gelbo flex tests conducted on the multi-layer ILPS system and on the single-layer MonstaBag system.

Sample Number	Temperature (°C)	Total Cycles	Observation(s)
ILPS Black Protective Shell 1	−40	2000	No apparent visual damage/degradation
ILPS White Structural Liner 1	−40	2000	No apparent visual damage/degradation
MonstaBag 1	−40	<15	Coating delamination and severe cracking
MonstaBag 2	−40	1	Coating “shattered” from woven fabric
ILPS Black Protective Shell 2	−50	2000	No apparent visual damage/degradation
ILPS White Structural Liner 2	−50	2000	No apparent visual damage/degradation
ILPS Black Protective Shell 3	−60	2000	No apparent visual damage/degradation
ILPS White Structural Liner 3	−60	2000	No apparent visual damage/degradation
ILPS White Structural Liner + Black Protective Shell 4	−60	2000	No apparent visual damage/degradation

5 Pre- and Post-UV Exposure Tensile Tests

We removed the Gelbo equipment from the MTS machine and installed textured 1 in. wide by 1 in. long grips (per ASTM D751 [ASTM 2011b], Figure 3) to conduct a series of tensile tests at room temperature (23°C) and at the minimum service temperature, −40°C. Tensile load was applied at a rate of 12 in./min. As noted above, the MonstaBag samples were eliminated from consideration during initial Gelbo flex tests; so we moved forward and conducted tensile tests on only the ILPS product. We measured and recorded tensile load and elongation for each test and gained a qualitative understanding of the ILPS fabric behavior at both room temperature and at −40°C. It was vital to determine if the failure mode changed from an elastic-plastic deformation at room temperature to a more brittle response at −40°C. Brittle, instantaneous failures have the potential to be more devastating in the field vs. slower developing plastic failures.

Figure 3. Aluminum adapter plates fabricated to accommodate modified (1 × 1 in.) MTS grips (left) to meet ASTM D751 specifications for tensile tests (ASTM 2011b). Sample secure in modified grip assembly and ready for testing (right).

In addition, we sent samples of the white structural liner for UV exposure testing at the ERDC Construction Engineering and Research Laboratory (CERL) in Champaign, IL. ERDC-CERL operates and maintains two UV exposure cabinets for testing the resistance of paints, coatings, fabrics, and other materials to UV irradiance. We designed our UV exposure tests to gain a basic understanding of the fabric's resistance to damaging UV irradiance in the Antarctic environment. We developed irradiance exposure rates from Bernhard et al. (2008) and determined that 30 days (24 hr/day) of exposure at an UVA spectrum intensity of 340 nm is approximately equal to 1 field season's exposure.

We conducted repeat (5 samples) tensile tests individually on the ILPS white structural liner and black protective shell materials under room temperature (23°C) and at cold conditions (−40°C). Because of a vendor mix-up where we did not receive an exact copy of the ILPS bags shipped to USAP, we were able to conduct UV exposure and subsequent tensile tests on only the white structural liner material. Table 3 presents the test configurations, average maximum loads, standard deviations, and qualitative observations; and Figures 4–6 present images from each test. Figure 7 illustrates strength degradation as a function of UV exposure time for the ILPS white structural liner fabric. Note that the tensile-test load rate was constant for all tests (12 in./min).

Table 3. Tensile tests conducted on room temperature and operational (field) temperature (pre- and post-UV exposed) samples of the ILPS multi-layer bulk-waste storage system.

Sample Numbers	Temp. (°C)	Avg. Max. Load (lb)	Std. Dev. (lb)	Observation(s)
ILPS Black Protective Shell L3–L7	23	112	13	No Slipping, uniform pull, weave "shreds" uniformly
ILPS White Structural Liner S1–S5	23	280	12	No slipping, uniform pull, fabric "shreds" uniformly without observed "edge effects"
ILPS Black Protective Shell L8–L12	−40	108	13	Very similar to shell failure
ILPS White Structural Liner S7–S11	−40	291	14	Elongates then "shreds" inward from edge
ILPS White Structural Liner S1–S6 (about 1 year UV Exposure)	−40	227	16	Pulls vertical fibers thin
ILPS White Structural Liner T1–T6 (about 3 years UV Exposure)	−40	170	8	Samples felt "gritty," short elongation to break
ILPS White Structural Liner T1–T6 (about 4 years UV Exposure)	−40	149	8	Samples felt "gritty" again, shorter elongation to break

Figure 4. ILPS black protective shell fabric (left) and white structural liner fabric (right) under load during ASTM D751 (ASTM 2011b) tensile tests. Note the use of modified clamp assemblies to meet the 1 × 1 in. grip requirement.

Figure 5. ILPS white structural liner fabric samples following tensile testing at −40°C. Left sample was not exposed to UV irradiation, and right sample was exposed to the equivalent of 1 year of UV irradiation.

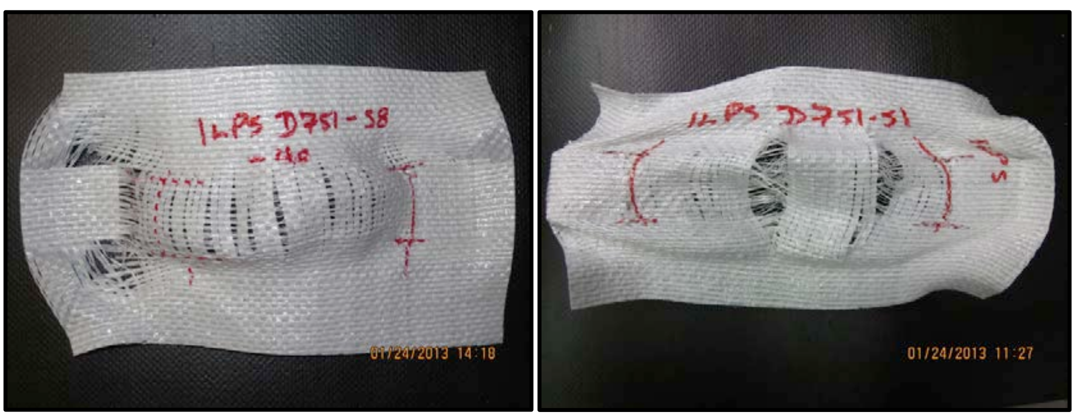


Figure 6. ILPS white structural liner fabric samples following tensile testing at −40 °C. The left samples additionally underwent a 3-year UV irradiation equivalent and the right sample a 4-year UV irradiation equivalent. Note the complete failure of fibers after 3 years of exposure. The 4-year samples produced similar results.

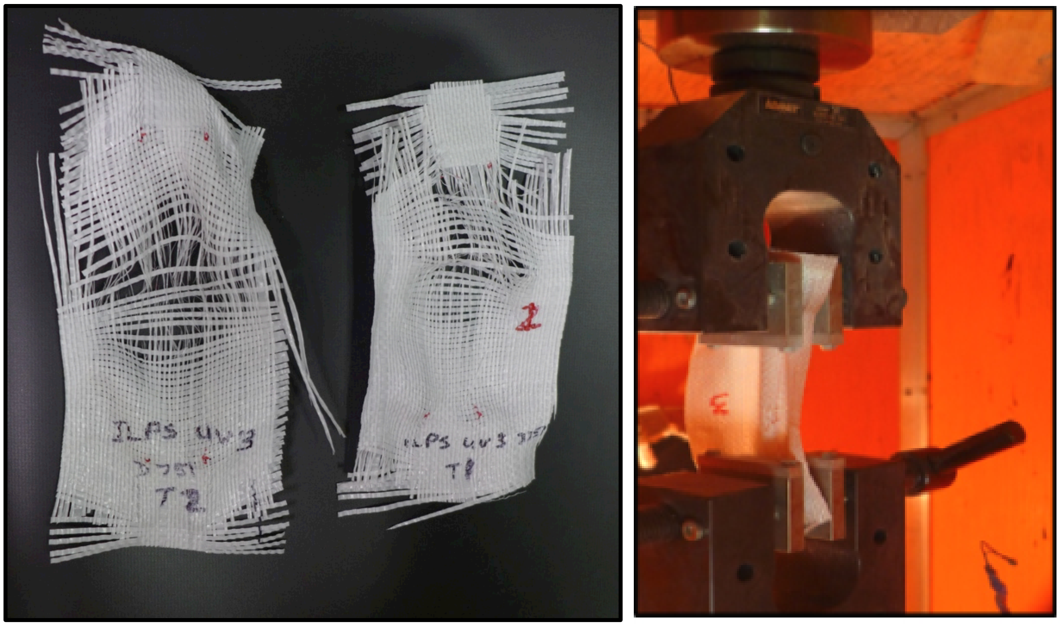
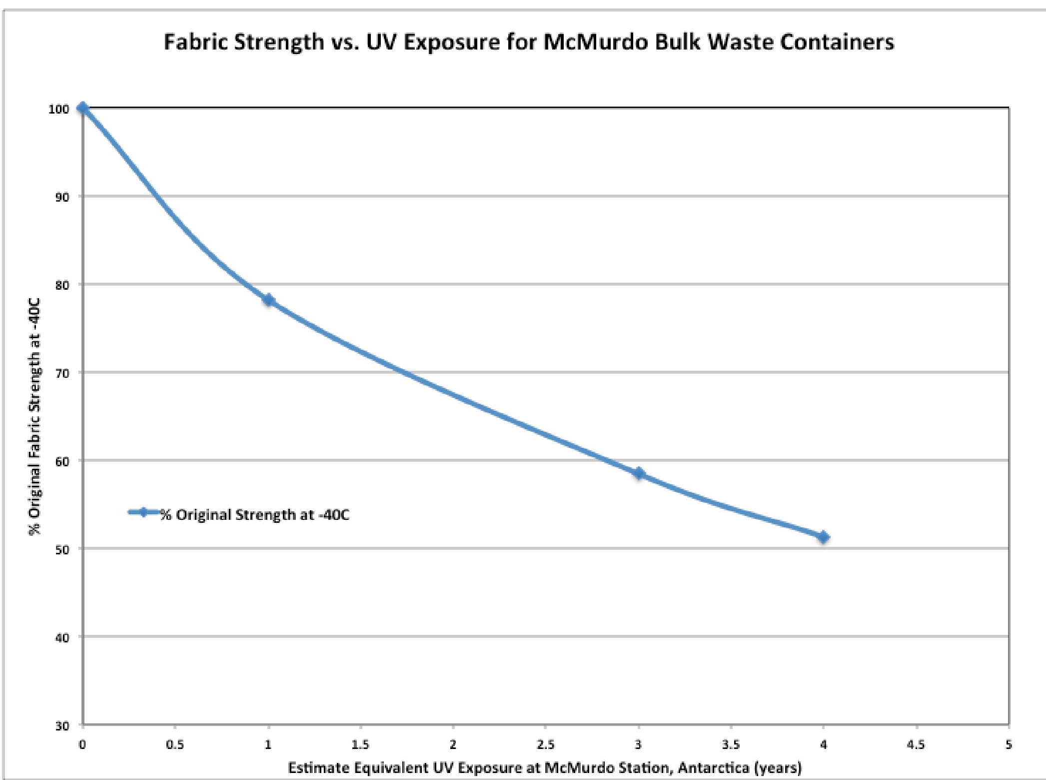


Figure 7. ILPS white structural liner fabric strength degradation from UV exposure expressed as a percentage of its original (no UV exposure) strength. All tests were conducted at −40 °C.



6 Discussion of Results

We set out to complete Gelbo flex tests (ASTM 2011a) and uniaxial tensile tests (ASTM 2011b) on the MonstaBag and ILPS products under consideration for use as bulk-waste containers for the USAP. The MonstaBag product shattered during the Gelbo flex tests conducted at −40°C, thus eliminating it from further evaluation. Subsequently, we conducted tensile tests of the coated fabrics used in the ILPS waste bags delivered to USAP. We tested both the internal white structural liner and the exterior black protective shell materials that make up the system.

The lightweight black external protective shell material's average maximum loads prior to failure were 112 ± 13 lbf at room temp (23°C) and 108 ± 13 lbf at −40°C, and the white interior structural liner material averaged 280 ± 12 lbf at room temp (23°C) and 291 ± 14 lbf at −40°C. Thus, there were negligible differences with respect to temperature effect as the results were within one standard deviation. Qualitatively the materials appeared to exhibit the same mechanism (elongation of fibers) prior to failure, which is beneficial for preventing failure in the field, compared with the stiffening and sudden rupture of some materials as they experience tensile stress near their brittleness temperature.

Following simulated UV exposure of 1, 3, and 4 years at McMurdo (1, 3, and 4 months, respectively, in the UV exposure cabinet at CERL), the white structural liner material averaged 227 ± 16 lbf, 170 ± 8 lbf, and 149 ± 8 lbf, respectively, at −40°C. This is a drop of 22%, 42%, and 49%, respectively, compared with new material tested at −40°C. We feel this strength loss from UV exposure is significant, and we discuss it below in the recommendations.

7 Conclusions and Recommendations

The USAP (through NSF and its vendors) provided CRREL with samples of two COTS bulk-waste storage bag materials: one fabric sample from MonstaBag and two full-size bags from ILPS. We conducted modified Gelbo flex tests on the black protective shell and the white structural liner fabric of the ILPS system and on the single-layer, bonded fabric MonstaBag system. The ILPS components and integrated system passed Gelbo evaluations at room temperature and at progressively lower field-service temperatures. The initial two MonstaBag samples failed at −40°C during Gelbo tests, and we concluded that the MonstaBag product did not meet environmental service requirements for the USAP and recommend that it be eliminated from further consideration.

We conducted tensile tests at room temperature and at the −40°C field service temperature on the ILPS components noted above. The cold tests generated negligible differences in material tensile behavior at the field service temperature (within one standard deviation of the room temperature tests). The ILPS system did not experience sudden, brittle, or catastrophic failures, thus indicating these systems will perform at the required field service temperatures.

In addition, we conducted tensile tests of the ILPS white structural liner fabric at −40°C following simulations (in a materials exposure cabinet) of approximately 1, 3, and 4 years of UV irradiation. The fabric retained 78%, 58%, and 51%, respectively, of its initial strength when compared with new (unexposed) structural material tested at the same temperature. Based on the test results following exposure to UV irradiation, we felt the drop in tensile strength was significant. There are a wide variety of potential sources for damage from rough handling, temperature swings, and loading. It is difficult to predict and thus design solutions for those issues, but we were able to predict the impact of UV irradiation and thus we recommend implementation of the ILPS (or similar) product into the USAP bulk-waste system with the condition that the structural liner is shielded from UV irradiation by a protective shell or by other means. We also recommend initiating a benefit-cost study to compare bulk-waste bags against the cardboard triwalls and other potential products to determine the most effective long-term solution.

Thus we conclude that the ILPS product meets Antarctic environmental service requirements with the condition that, without a recommended black fabric protective shell, long-term, direct exposure of the white structural liner material to UV irradiation can cause severe degradation that can lead to catastrophic failure of the fabric.

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14. ABSTRACT

The National Science Foundation's United States Antarctic Program (NSF-USAP) is constantly striving to introduce materials, methods, and equipment that will increase efficiency and reduce costs of their logistics and operations activities. Storage and transportation of bulk waste is a resource-intensive task for the USAP; and the introduction of high performance fabric containment and transport products, because they are cheaper, take up less volume when empty, and are lighter than the existing waste bins, could improve waste operations. We adapted standard test methods to represent Antarctic conditions to allow us to evaluate the behavior of high performance fabrics for the USAP.

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15. SUBJECT TERMS

Cold fabric strength	Fabric container strength	Polar fabrics
EPOLAR	GELBO flex	Polar waste transport
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