ARMY RESEARCH LABORATORY

Laboratory Evaluation of Nitrile Fuel Tank Materials (Phase II)

by James M. Sloan, David Flanagan, Daniel DeSchepper, Paul Touchet, and Henry Feuer

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14. ABSTRACT

We have evaluated seven candidate nitrile-coated fabrics for use in collapsible fuel storage containers that we received from four suppliers, Bulk Liquid Storage Systems (BLSS), Avon Engineered Fabrications (AEF), Berg Inflatable Systems (BIS) and Dunlop Corporation. Four of the materials BLSS, Berg/Reeves, AEF/Reeves, and AEF/Archer met the MIL-PRF-32233 JP-8 fuel diffusion requirement of 0.06 oz/ft^2/24 h. The JP-8 diffusion rates for the remaining three materials did not meet the military specification. All materials performed well in peel adhesion testing when conditioned with fuels; however, when conditioned with water at elevated temperatures a major decrease in strengths are observed. The Dunlop fabric seam performed poorly retaining only 20% of its original peel strength. The reduction was only 50% when extraction with JP-8 was performed before water conditioning.

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1. Introduction

Collapsible fabric fuel tanks have provided critical tactical bulk petroleum storage for military operations for over 50 years. Beginning in the 1940s with the 900–3000-gal pillow tanks, collapsible fabric tanks have evolved into the primary tactical fuel storage vessels now used by all of the military services (*1*). Initially, fabric tanks were used to supplement large, bolted steel fuel storage tanks and to store small quantities of fuel in remote locations. Early collapsible tanks were made from thick, nitrile thermoset rubber-coated fabric materials that were heavy and required several Soldiers and a significant amount of materials-handling equipment to deploy.

Technological advances in materials and fabrication techniques led to the manufacture of larger and lighter-coated fabric tanks made from thinner thermoplastic urethane-coated fabrics. The new technologies permitted the development, manufacture, and fielding of collapsible tanks with capacities over 200,000 gal. These tanks can be deployed rapidly and recovered using fewer personnel and less equipment. The success of the large-capacity collapsible tank rendered the labor-intensive bolted tanks obsolete, and they were removed from the Army inventory.

The U.S. Army currently has a large number of fabric reinforced elastomer tanks ranging in size from 100 to 210,000 gal used for the storage of fuels and water in the field. Examples of 50,000 gal fuel tanks are shown in figure 1. Collapsible fuel tanks, fabricated from urethane-coated nylon fabric, were first introduced by the military during the Vietnam conflict. Their performance, particularly in humid tropic environments, has been less than satisfactory. Unless formulated and produced according to stringent limitations, urethane-based fabric coatings were extremely susceptible to ultraviolet and hydrolytic degradation. At that time, tanks had to hold high aromatic gasoline, as well as diesel and jet propellant (JP) fuels. The only urethane that could handle the high aromatic gasoline fuels was the polyester urethane resins, which was more vulnerable to hydrolysis than the polyether urethane. Advancements were made in better understanding the mechanism of the degradation process in the 1980s. Suppliers then added hydrolytic stabilizers to the polyester urethanes to prolong their service life. The problem continued to linger, resulting in the deterioration and ultimate failure of external tank surfaces and seams, even when protective agents had been incorporated into the tank coatings (*2*–*4*).

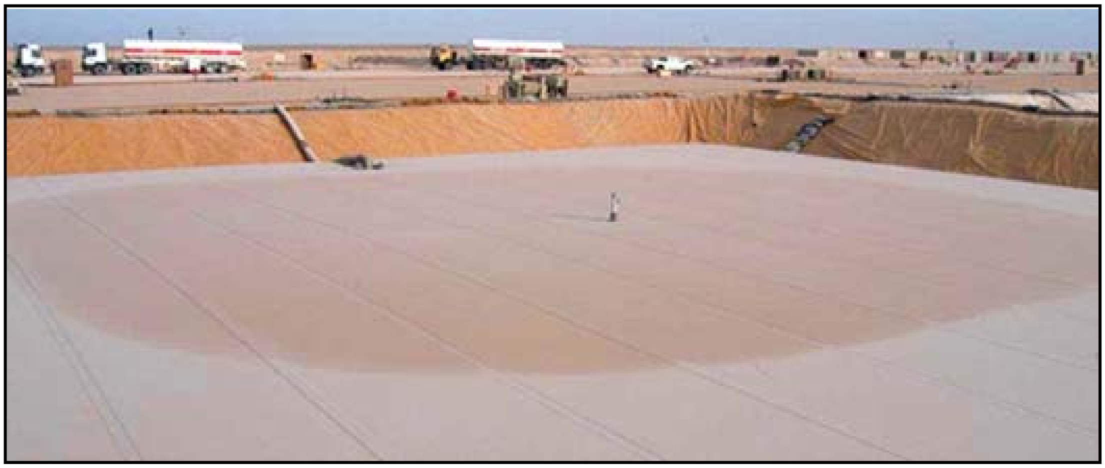

Figure 1. Typical coated fabric fuel/storage tank, showing wet spot on top panel surrounding the pressure release valve.

In 1990, the U.S. Army issued a directive that these tanks would no longer be used by the Army for long-term storage of gasoline fuels. This change in policy allowed a shift in emphasis from high aromatic (gasoline) fuel-resistant coatings to more hydrolytically stable materials; thus, polyether urethanes could now be given more consideration as candidate fabric coatings. Concurrently, the U.S. Army readdressed and focused on determining the causes of coating and seam failures (*5–8*). Those studies demonstrated unequivocally that those failures were attributable to the leaching out of protective stabilizers from tank materials by contact with fuel puddles on the outer tank surface. The leaching action occurs regardless of the fuel type, but it is particularly severe in the case of diesel fuel. Because of this fuel's low volatility and slower evaporation rate, any puddles on the tank surface prolong the extraction process, resulting in more extensive damage. Examples of fuel storage tank fabrics that have exhibited leaking of fuel to form puddles are shown in figure 2.

(a) (b)

Figure 2. (a) Fabric delaminations of inservice fuel storage tanks and (b) large coating to fabric bonding failure due to surface fuel pooling and leaching.

Collapsible fuel storage containers recently deployed by the U.S. military in Iraq encountered surface temperatures approaching 180 °F. These tanks had never been deployed for an extended period in that type of environment before. Consequently, these coated fabric fuel tanks experienced catastrophic failures at an alarming rate. These failures have forced the U.S. Army to consider changes in the current testing methods used in the evaluation of materials and seams used in the construction of these storage containers with tests that more closely simulate the actual service conditions of fuel tanks being used in Southwest Asia (SWA). New test procedures introduced in this work included determining breaking strength and peel adhesion of tank seams at 200 °F and running dead load resistance of tank seams while immersed in fuel at 160 °F. Water immersion tests were conducted on fuel-extracted materials at 180 °F for up to 90 days.

2. Experimental

2.1 Tests Conducted

The tests were performed according to the appropriate paragraphs of the *Performance Purchase Description ATPD 2266* dated 6 June 2000, for *Tanks, Fabric, Collapsible: 3000, 10,000, 20,000, and 50,000 Gallon, Fuel* (*9*) and the American Society for Testing and Materials (ASTM) test methods as cited in tables 1 and 2. Certain aspects of the test plan, such as prolonged immersion in water, immersion in three test fuels (diesel fuel, JP-8, and reference fuel B), water immersion at a elevated temperature (180 °F), and performing a seam dead load tension tests while immersed in JP-8 fuel at 160 °F, deviated from the specification being used in this study.

This test plan was designed as an attempt to better understand recent tank failures observed in SWA and Iraq, where more severe environmental conditions are encountered. Seam peel, breaking strength and dead load tension testing were performed at an elevated temperature of 200 °F, to attempt to simulate the highest reported skin temperatures that the tanks could experience in the SWA theater due to solar loading. Because no data was available at the start of this program, the 200 °F temperature was selected and considered as the worst case highest temperature the surface of the fuel tanks possibly would encounter; thus, the seam peel and breaking strengths were evaluated at this temperature, in addition to room temperature testing. To our knowledge, this is the first time seam strength has ever been evaluated in this manner.

Table 1. Coated fabric testing methods.

Coated Fabric Tests	Coated Fabric Test Methods	
	ATPD 2266 Para	ASTM Test Methods
1. Coated Fabric Weight, oz/yd^2	4.5.4	D 3776 or D 751
2. Diffusion, JP-8 at Room Temp, fl oz/ft^2/24 h	4.5.4.1	—
3. Diffusion, JP-8 at 160 °F, fl oz/ft^2/24 h	4.5.4.1	—
4. Diffusion, Diesel at Room Temp, fl oz/ft^2/24 h	4.5.4.1	—
5. Diffusion, Reference Fuel B at Room Temp., fl oz/ft^2/24 h	4.5.4.1	—
6. Diffusion, Reference Fuel B at 160 °F, fl oz/ft^2/24 h	4.5.4.1	—
7. As Received and After Creased at −25 °F, fl oz/ft^2/24 h		
a. Diffusion with JP-8 Fuel	4.5.4.3	—
b. Diffusion with Diesel Fuel	4.5.4.3	—
c. Diffusion with ASTM Reference Fuel B	4.5.4.3	—
8. After Extraction with JP-8 Fuel and Creased at −25 °F, fl oz/ft^2/24 h		
a. Diffusion with JP-8 Fuel	4.5.4.3 and 4.5.7	—
b. Diffusion with ASTM Reference Fuel B	4.5.4.3 and 4.5.7	—
9. After Extraction with Diesel Fuel and Creased at −25 °F, fl oz/ft^2/24 h		
a. Diffusion with JP-8 Fuel	4.5.4.3 and 4.5.7	—
b. Diffusion with ASTM Reference Fuel B	4.5.4.3 and 4.5.7	—
10. After Extraction with ASTM Fuel B and Creased at −25 °F, fl oz/ft^2/24 h		
a. Diffusion with JP-8 Fuel	4.5.4.3 and 4.5.7	—
b. Diffusion with ASTM Reference Fuel B	4.5.4.3 and 4.5.7	—
11. Tear Strength, Warp, lb	4.5.4	D 751, Procedure B
12. Tear Strength, Fill, lb	4.5.4	D 751, Procedure B
13. Breaking Strength, Warp, lb/in	4.5.4	D 751, Procedure B
14. Breaking Strength, Fill, lb/in	4.5.4	D 751, Procedure B
15. Puncture Resistance, As-Received, lb		
a. As-Received, lb	4.5.4.2	D 751
b. After JP-8 Extraction and Immersed 28 Days in Water at 180 °F, lb	4.5.4.2 and 4.5.7	D 751
c. After Accelerated Weathering for 1500 h, lb	4.5.4 and 4.5.3.2	D 751
d. After JP-8 Extraction and Accelerated Weathering for 1500 h, lb	4.5.4, 4.5.7 and 4.5.3.2	D 751
16. Weather Resistance, Stretched 5%, Breaking Strength, Warp, lb/in	4.5.4 and 4.5.3.2	D 750 and D 751, Procedure B

Table 1. Coated fabric testing methods (continued).

Coated Fabric Tests	Coated Fabric Test Methods	
	ATPD 2266 Para	**ASTM Test Methods**
17. Weather Resistance, Stretched 5%, Breaking Strength, Fill, lb/in	4.5.4 and 4.5.3.2	D 750 and D 751, Procedure B
18. Weather Res. After JP-8 Extraction, Stretched 5%, Warp, lb/in	4.5.7, 4.5.4 and 4.5.3.2	D 750 and D 751, Procedure B
19. Weather Res. After JP-8 Extraction, Stretched 5%, Fill, lb/in	4.5.7, 4.5.4 and 4.5.3.2	D 750 and D 751, Procedure B
20. Torsional Stiffness and Young’s Modulus Properties,		
a. As-Received	4.5.4	D 1053
b. After Extraction with JP-8 Fuel and Dried	4.5.4 and 4.5.7	D 1053
c. After Accelerated Weathering 1500 h	4.5.4	D 750 and D 1053
21. Dynamic Mechanical Analysis Properties, E', E", and Torsional Stiffness, psi		
a. As-Received	4.5.4	D 4065
b. After Extraction with JP-8 Fuel and Dried	4.5.4 and 4.5.7	D 4065
c. After Accelerated Weathering 1500 h	4.5.4	D 750 and D 4065

Table 2. Coated fabric seam testing methods.

Seam Tests	**Seam**	**Test Methods**
	ATPD 2266 Paragraph	**ASTM Test Methods**
1. Original Properties		
a. Breaking Strength at Room Temp., lb/in	4.5.5.1	D 751, Method B
b. Peel Adhesion at Room Temp., lb/in	4.5.5.1	D 413, Machine Method
2. After Immersion in Diesel Fuel or Fuel B for 14 Days at 160 °F		
Tested at Room Temp.		
a. Breaking Strength at Room Temp., lb/in	4.5.5.1	D 751, Method B, D 471
b. Peel Adhesion at Room Temp., lb/in	4.5.5.1	D 413, Machine Method, D 471
3. After Water Immersion for 28, 42, and 70 Days at 180 °F		
Tested at Room Temp.		
a. Breaking Strength, lb/in	4.5.5.1	D 751, Method B, D 471
4. After JP-8 Extraction, Water Immersion for 14 Days at 180 °F		
Tested at Room Temp.		
a. Breaking Strength, lb/in	4.5.5.1 and 4.5.7	D 751, Method B, D 471
b. Peel Adhesion, lb/in	4.5.5.1 and 4.5.7	D 413, Machine Method, D 471
5. After JP-8 Extraction, Water Immersion for 28 Days at 180 °F		
Tested at Room Temp.		
a. Breaking Strength, lb/in	4.5.5.1 and 4.5.7	D 751, Method B, D 471
6. After JP-8 Extraction, Water Immersion for 42 Days at 180 °F		
Tested at Room Temp		
a. Breaking Strength, lb/in	4.5.5.1 and 4.5.7	D 751, Method B, D 471
b. Peel Adhesion, lb/in	4.5.5.1 and 4.5.7	D 413, Machine Method, D 471
7. After JP-8 Extraction, Water Immersion for 70 Days at 180 °F		
Tested at Room Temp.		
a. Breaking Strength, lb/in	4.5.5.1 and 4.5.7	D 751, Method B, D 471
b. Peel Adhesion, lb/in	4.5.5.1 and 4.5.7	D 413, Machine Method, D 471

2.1.1 Coated Fabric Tests

1. Coated Fabric Weight—Determine coated fabric weight by measuring the weight of three 2 × 2 in specimens of the coated fabric according to option C of ASTM D 3776 or ASTM D 751, paragraph 10, and report in ounces per square yard.

2. Original Breaking Strength—Determine breaking strength as received by using three 1 × 6 in coated fabric specimens as received and the breaking strength performed according to ASTM D 751, procedure B (Cut Strip Test Method) and reported in pounds per inch (lb/in). Cut samples in the warp (machine direction) and the fill (cross) directions and test and report separately.

3. Breaking Strength After Accelerated Weathering—Cut two breaking strength specimens (1 × 6 in) from each panel (3.25 × 6.5 in) that have been stretched 5% and conditioned in the weatherometer in accordance with ASTM D 751 for 1500 h. The breaking strength is performed on three specimens as described in ASTM D 751, section 2.1.A.2.

4. Original Tear Strength—Perform tear strength according to ASTM D 751, procedure B (Tongue Tear Test Method) using coated fabric specimens 8 × 3 in wide with a 3 in long cut in the center of the 3 in width and reported in pounds. Cut the specimens to be used for the warp direction with the longer dimension parallel to the cross-machine direction.

5. Original Puncture Resistance—Perform puncture resistance test using three 3.75 in diameter specimens cut from the coated fabric and performed according to ASTM D 751, except that the ring clamp mechanism has an internal diameter of 3.00 in and reported in pounds.

6. Puncture Resistance after JP-8 Fuel Extraction and Immersion in Water at 180 °F—The 3.5 in diameter coated fabric specimens are immersed in JP-8 fuel of MIL-T-83133 for at least seven days at 160 °F and dried using a vacuum oven. The dried specimens are then immersed in distilled or deionized water for 28 days at 180 °F. The water with the specimens is allowed to cool to room temperature. The specimens are immediately removed from the water and the puncture test performed as described in ASTM D 751, section 2.1.A.5.

7. Puncture Resistance After Accelerated Weathering—Coated fabric panels 5 × 6.5 in are exposed (exterior surface facing the light source) in the weatherometer in accordance with ASTM D 750 for 1500 h. From these panels, the 3.75 in diameter specimens are cut and the puncture test performed as detailed in ASTM D 751, section 2.1.A.-5.

8. Puncture Resistance After JP-8 Extraction and Accelerated Weathering—Coated fabric panels 5 × 6.5 in are immersed in JP-8 fuel of MIL-T-83133 for at least seven days at 160 °F and dried using a vacuum oven at 120 °F for 16 ± 2 h at a vacuum above 20 in of

mercury. The dried panels are then exposed (exterior surface facing the light source) in the weatherometer in accordance with ASTM D 750 for 1500 h. From these panels, the 3.75 in diameter specimens are cut and the puncture test performed as detailed in ASTM D 751, section 2.1.A-5.

9. Ozone Resistance as Received—Ozone resistance is tested according to ASTM D 1149 using test specimen B (3.75 × 1 in) tested in the form of a bent loop. Two conditions are used:

   - Conditioned 14 days at 104 ± 4 °F in air having a partial pressure of ozone of 50 mPa.
   - Conditioned 14 days at 160 ± 5 °F in air having a partial pressure of ozone of 50 mPa.

Number of days until the appearance of first crack is recorded. Experiment is performed for 14 days.

10. Fuel Diffusion at Room Temperature—Three coated fabric disks (3 in) are used to perform the fuel diffusion tests. The test apparatus consists of aluminum diffusion cups with screw top rings. The inside diameters of the cups and rings will be 2 in and the cup is 1 in deep. The cup ring assembly weight should be kept around 120 g to allow a suitable analytical balance to be used to weigh the cups with coated fabric and fuel. The cup is filled with ~1.4 fluid ounces of test fuel (JP-8 of MIL-T-83133, diesel of A-A-52557, or ASTM reference fuel B of ASTM D 471). An 80% solution of Elvamide 8061 Nylon resin in methanol is used to seal the exposed fabric around the edge of the test coated fabric disk and on both surfaces coming into contact with the diffusion cup flange. The test disk is placed over the cup containing the test fuel with the coated fabric material “interior” side facing the fuel. The screw top is tightened securely and retightened at least an hour later. The diffusion cup assembly (with face up) is placed on a suitable rack in a constant temperature chamber controlled at 73.3 ± 2 °F and a relative humidity of 65% ± 5%. Allow 1 h for the assembly to reach equilibrium, then weigh the cup assembly to the nearest 0.005 g and place assembly back on rack face up and return the rack to the constant temperature chamber. After 24 h, weigh and check each assembly for vapor loss. Retorque the cup top if necessary. Invert the cup assemblies with test disk facing down in a rack that permits free access of air to test disk. Weigh the cup assemblies daily. Continue to weigh daily until the weight loss is constant to within 0.010 g per day after two 24 h periods. Then record the daily loss for a continuous interval of 72 h. The diffusion rate (D) in fluid ounces per square foot per 24 h will be the average of not less than three specimens when calculated from the expression: $D = (144 \times (\text{average daily loss in grams}))/((\text{Sp. Gr.}) \times (29.573) \times (3.142) \times (R^2))$, where Sp. Gr. is the specific gravity of the test fuel, and R is the inside radius (1 in) of the test cup.

11. Fuel Diffusion at 160 °F—This test is conducted the same as described in ASTM E96-80, except that the cup assemblies are conditioned in an oven controlled at 160 ± 5 °F.

12. Fuel Diffusion at Room Temperature After Creased at –25 °F—Three coated fabric test panels 8 × 8 in are folded in half in each direction with the outside surface of the coated fabric facing out and so that the folded corner occurs in the center of each panel when unfolded. Place each folded panel under a 4 lb or more load and condition to <–25 °F for a minimum of 46 h in a low-temperature chamber. At the end of the conditioning period, unfold the panels in the chamber while the panels are still at a temperature <–25 °F and examine visually. Cracking, peeling, or delamination of any coating will constitute failure. The panels that pass this test are subjected to the diffusion test detailed in ASTM E96-80 above except that the disk specimens are cut so that the center of the folds coincides with the center of the diffusion cup. The diffusion test is performed with all three test fuels (ASTM reference B of ASTM D 471, diesel of A-A-52557, and JP-8 of MIL-T-83133).

13. Fuel Diffusion at Room Temperature After Fuel Extraction and Creased at –25 °F—Three coated fabric test panels 8 × 8 in are immersed in each of the three test fuels for seven days at 160 ± 5 °F and then dried in a vacuum oven for 16 ± 2 h at 120 °F under at least 20 in of mercury vacuum. The panels are then conditioned as in A.16 and diffusion performed as described in ASTM E96-80, except that only JP-8 of MIL-T-83133 and ASTM reference fuel B of ASTM D 471 will be used in the diffusion test for each of the three fuel-extracted materials.

14. Torsional Stiffness Properties of Unaged Coated Fabric Materials—The torsional stiffness properties of the coated fabric materials are performed using type B specimens and performed according to ASTM D 1053. The test for Torsional Stiffness and Young's modulus is performed at +72, +32, and –25 °F and reported in pounds per square inch.

15. Torsional Stiffness Properties After Accelerated Weathering—Condition a 3.25 × 6.5 in coated fabric panel in the weatherometer in accordance with ASTM D 750 for 1500 h. From this panel, cut the type B specimens and condition and test according to ASTM D 1053 as described in ASTM D 750, section 2.1.A.18.

16. Torsional Stiffness Properties after Fuel Extraction and Dried—Immerse 2 × 6 in panel of coated fabric in JP-8 fuel of MIL-T-83133 for seven days at 160 °F then dried in a vacuum oven for 16 ± 2 h at 120 °F under at least 20 in of mercury vacuum. From this panel, cut the type B specimens and test according to ASTM D 1053.

17. The thermoviscoelastic behavior of the elastomers was determined using a Hi-Res Dynamic Mechanical Analyzer (DMA) 2980 (TA Instruments) operated at a single frequency of 1.0 Hz. In each experiment, a polymer film of ~15–20 mm long, 7–8 mm wide and 0.07–0.10 mm thickness was used. The storage modulus (E') and loss modulus (E'') were measured after thermal equilibrium for 5 min at –100 °C, followed by an eventual heating to 120 °C at 2 °C/min.

2.1.2 Coated Fabric Seam Tests

1. Original Seam Breaking Strength at Room Temperature—Three seam breaking strength specimens 1 in wide (parallel to the seam) and extending (perpendicular to the seam) 3 in beyond both edges of the seam are used and tested at room temperature in accordance with ASTM D 751. Reported values are expressed in pounds per inch and failure within the seam on any specimen constitutes failure of this test.
2. Original Seam Peel Adhesion at Room Temperature—Three peel adhesion specimens 1 in wide (perpendicular to the seam) and of sufficient seam length to determine both the initial and after conditioning tests on the same specimen are used and tested at room temperature in accordance with ASTM D 413, Machine Method. Reported values are expressed in pounds per inch of width.
3. Seam Breaking Strength and Peel Adhesion Tested at 200 °F—For breaking strengths, the tests will be conducted as described in ASTM D 75, sections 2.1.B.1 and 2.1.B.2. For this testing, the specimens will be conditioned for 4 h at 200 °F prior to running the experiment. A thermo insulated jacket with temperature control allows the experiment to be conducted at 200 °F. For peel adhesions, ASTM D 413 is used following the same conditioning protocols.
4. Seam Breaking Strength Tested at Room Temperature After Immersion in Diesel and ASTM reference fuel B—Three seam breaking strength specimens 1.00 in wide (parallel to the seam) and extending (perpendicular to the seam) 3 in beyond both edges of the seam are immersed in diesel fuel of A-A-52557 and ASTM reference fuel B of ASTM D 471 for 14 days at 160 °F. No part of the test specimens will be coated or covered prior to the immersion test. Specimens will be stabilized in the immersion fluid at 73 ± 5 °F for 30 to 90 min before testing. Testing of immersed specimens, as described in ASTM D 751, section 2.1.B.1, will be completed within 3 min of removal from the immersion fluid.
5. Peel Adhesion Tested at Room Temperature After Immersion in Diesel and ASTM reference fuel B—Three peel adhesion specimens 1 in wide and of sufficient length to determine both the initial and after conditioning tests on the same specimen are immersed in diesel fuel of A-A-52557 and ASTM reference fuel B for 14 days at 160 °F. No part of the test specimens will be coated or covered prior to immersion test. Specimens will be stabilized in the immersion fluid at 73 ± 5 °F for 30 to 90 min before testing. Testing of immersed specimens, as described in ASTM D 751, section 2.1.B.2, will be completed within 3 min of removal from the immersion fluid.
6. Seam Breaking Strength and Peel Adhesion Tested at 200 °F After Immersion in Diesel and ASTM reference fuel B—For breaking strengths, the tests will be conducted as described in ASTM D 751 sections 2.1.B.4 and 2.1.B.5, except that the specimens will be conditioned for 4 h at 200 °F prior to running the test while the specimens are maintained at 200 °F. For peel adhesions, ASTM D 413 is used following the same conditioning protocols.

7. Seam Breaking Strength and Peel Adhesion Tested at Room Temperature After Immersion in Water–For breaking strengths, tests will be conducted as described in ASTM D 751 sections 2.1.B.4 and 2.1.B.5, except that the immersion fluid will be distilled or deionized water. The immersion periods will be 28, 42, and 70 days at 180 °F. For peel adhesions, ASTM D 413 is used following the same conditioning protocols.
8. Seam Breaking Strength and Peel Adhesion Tested at 200 °F After Immersion in Water—For breaking strengths, tests will be conducted as described in ASTM D 751 section 2.1.B.6. The immersion fluid will be distilled or deionized water. The immersion time intervals will be 28, 42, and 70 days at 180 °F. For peel adhesions, ASTM D 413 is used following the same conditioning protocols.
9. Seam Breaking Strength and Peel Adhesion Tested at Room Temperature After JP-8 Extraction and Immersion in Water—For breaking strengths, three tests specimens as described in ASTM D 751 sections 2.1.B.1 and 2.1.B.2 are immersed in JP-8 fuel of MIL-T-83133 for at least seven days at 160 °F and then dried in a vacuum oven for 16 ± 2 h at 120 °F under at least 20 in of mercury vacuum. The dried specimens are conditioned and tested as described in ASTM D 751 section 2.1.B.7. For peel adhesions, ASTM D 413 is used following the same conditioning protocols.
10. Seam Breaking Strength and Peel Adhesion Tested at 200 °F After JP-8 Extraction and Immersion in Water—For breaking strengths, three tests specimens as described in ASTM D 751 sections 2.1.B.1 and 2.1.B.2 are immersed in JP-8 fuel of MIL-T-83133 for at least seven days at 160 °F and then dried in a vacuum oven for 16 ± 2 h at 120 °F under at least 20 in of mercury vacuum. The dried specimens are conditioned and tested as described in ASTM D 751 section 2.1.B.8. For peel adhesions, ASTM D 413 is used following the same conditioning protocols.
11. Dead Load Shear Resistance at 200 °F—Three test specimens 1.00 in wide (parallel to the seam) and extending (perpendicular to the seam) 3.00 in beyond both edges of the seam are used. One index mark will be scribed on each side of the seam to facilitate observation and measurement of slippage. Each specimen is subjected to a constant (dead load) tension force of 100.00 ± 0.50 lb at 200 ± 5 °F for 8 h. At the end of 8 h, each specimen is examined, while still under tension, for signs of slippage. Slippage, by any specimen greater than 0.125 in will constitute failure of the test.

3. Discussion

3.1 Base Coated Fabric Properties

3.1.1 Fuel Diffusion

Figure 3 shows the fuel diffusion results for three very different fuels: JP-8, diesel fuel, and ASTM reference fuel B. The daily diffusion rates for JP-8 and diesel fuel were very low for all the nitrile-coated fabric materials at standard room temperature conditions. Four of the materials (Bulk Liquid Storage Systems [BLSS], Berg/Reeves, Avon Engineered Fabrications (AEF)/Reeves, and AEF/Archer) met the MIL-PRF-32233 JP-8 fuel diffusion requirement of 0.06 fl oz/ft^2/24 h. The JP-8 diffusion rates for the remaining three materials did not meet the military specification and were marginally higher where the rates ranged from 0.0645 to 0.091 fl oz/ft^2/24 h. The Berg/Reeves material is currently being used by Berg to fabricate and supply fuel tanks to the military. The BLSS material has a tan colored nitrile rubber exterior with a black colored interior coating, which has a thin plastic film outer layer of polyvinyl fluoride (PVF) to assist as a barrier to fuel.

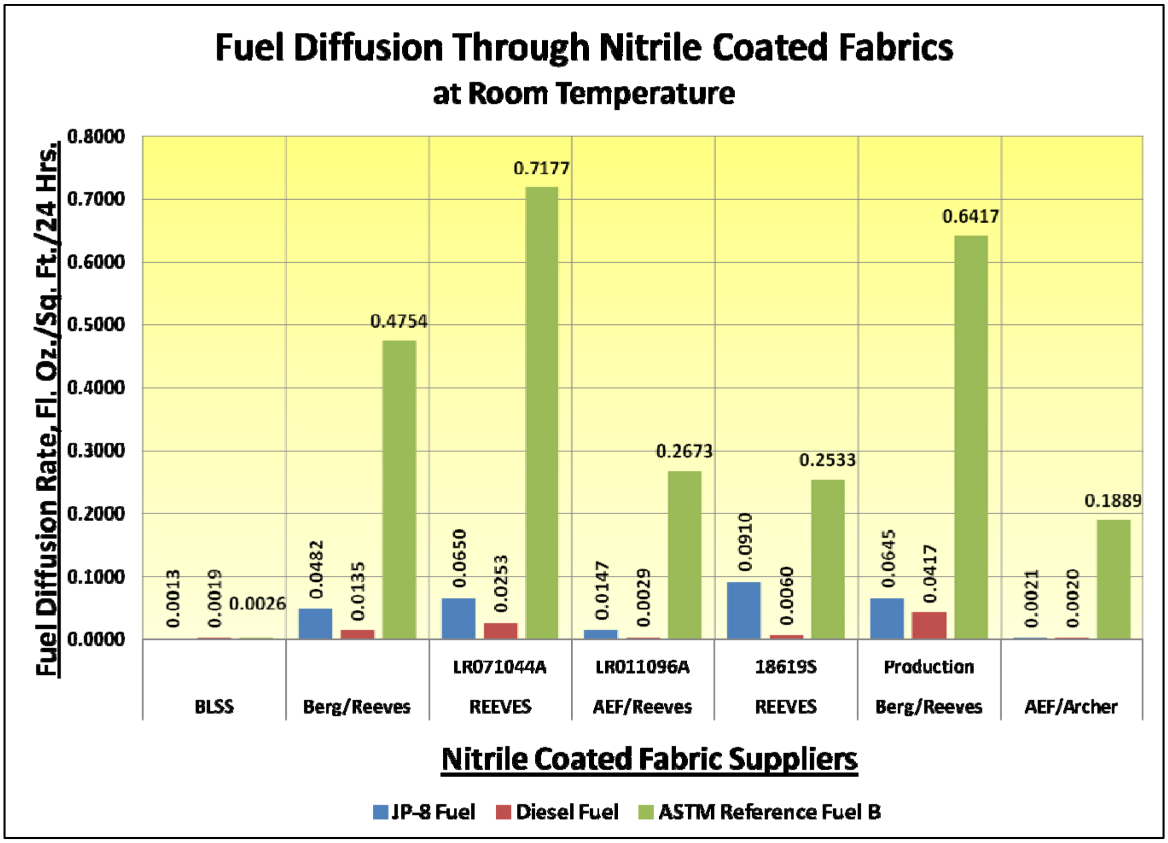

Figure 3. Permeation results for JP-8, diesel, and ASTM reference B fuel through nitrile-coated fabrics. Experiments conducted at room temperature.

Figure 3 also presents the diffusion rates for diesel fuel at ambient temperature. For all nitrile materials studied, the diffusion rates measures for diesel fuel were significantly lower than the rates measured for JP-8. Diesel fuel diffusion rates varied from 0.0019 to 0.047oz/ft^2/24 h, which are all very low. JP-8 diffusion rates varied from 0.0021 to 0.091 oz/ft^2/24 h, which are also low.

Diffusion was also performed at ambient temperature with the ASTM reference fuel B. ASTM reference fuel B has a composition 30% aromatic content (toluene) and 70% iso-octane (commercial gasoline). This fuel designed to simulate Mogas (military gasoline) is more volatile than the two other fuels and is expected to cause a higher diffusion rate. MoGas also contains a small amount of alcohol, which is not present in the ASTM fuel. The diffusion rate measured varied from a low of 0.1889 to a high of 0.7177. This is approximately 10 to 90 times greater than the measured diffusion rate with JP-8 fuel. The lone exception to this range was the BLSS nitrile, which had a rate of 0.06. These diffusion rates for ASTM reference fuel B are unacceptably high for nitrile-coated fabrics, suggesting that nitrile-coated fuel storage containers might not be suitable storing this fuel.

Figure 4 compares the diffusion rates of JP-8 at ambient temperature and at 160 °F. When fuel tanks are deployed in desert environments, it is not unusual for skin temperatures to exceed 140 F. It becomes important and relevant to evaluate diffusion and strength properties at elevated temperatures to predict in-field performance. Not surprisingly, when the test temperature was elevated to 160 °F, the diffusion rate increased significantly. All three of the Berg/Reeves materials exhibited an order of magnitude increase in diffusion rate at 160 °F. The BLSS nitrile showed an order of magnitude increase but the resulting diffusion rate at 160 °F of 0.038 was unexpectedly low. The AEF/Archer nitrile diffusion rate of 0.149 was also considered very low and acceptable.

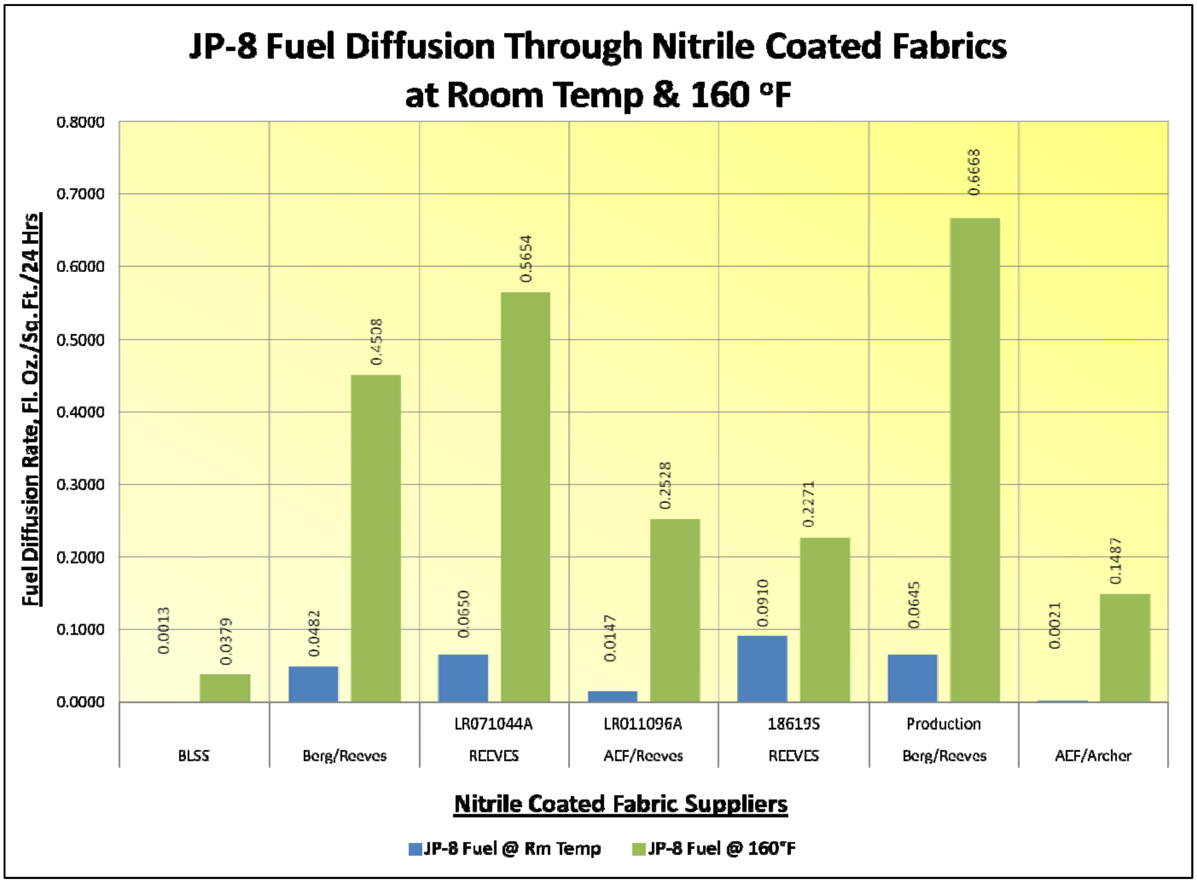

Figure 4. Effect of temperature on the permeation properties of nitrile-coated fabrics.

The diffusion rate results are tabulated in table 3. Five of the nitrile materials when creased at low temperature exhibited minor difference in fuel diffusion. However, the BLSS and AEF/Archer 4111 materials exhibited cracks in the nitrile coating and as a result failed the crease test. When the nitrile fabrics were pretreated with fuel immersion, the fabrics failed the crease test by exhibiting significant cracking throughout the coating layer. Consequently, tanks made from these materials would not be able to be deployed at –25 °F. After a tank has been in service, fuel can extract plasticizers from the tank nitrile coating materials, which can cause the coated fabric to become extremely stiff and brittle resulting in an appreciable amount of cracking at –25 °F.

Table 3. Summary of diffusion results for nitrile-coated fabrics.

Fabric Supplier	**Reeves**	**Reeves**	**BLSS**	**AEF**	**AEF**	**Berg**	**Berg**	**GMA Covers**
Fabric Manufacturer	**Reeves**	**Reeves**	**BLSS**	**Archer**	**Reeves**	**Reeves**	**Reeves**	**Musthane**
Fabric Manufacturer Number	**LR071044A**	**18619S**	**—**	**4111**	**LR011096A**	**First Sample**	**Production**	**—**
Fuel Diffusion at Standard Conditions (73 °F and 65% Humidity)								
As-Received, fl oz/ft^2/24 h								
With ASTM Fuel B	0.7177	0.2533	0.0026	0.1889	0.2673	0.4754	0.6417	0.0383
With JP-8	0.0650	0.0910	0.0013	0.0021	0.0147	0.0482	0.0645	0.0102
With Diesel Fuel	0.0253	0.0060	0.0019	0.0020	0.0029	0.0135	0.0417	0.0088
As-Received and After Creased at −25 °F, fl oz/ft^2/24 h								
With ASTM Fuel B	0.6877	0.3429	F[a]	F	0.3050	0.5260	0.6854	0.0376
With JP-8	0.0444	0.0142	F	F	0.0143	0.0393	0.0471	0.0114
With Diesel Fuel	0.0083	0.0065	F	F	0.0056	0.0109	0.0150	0.002
After Extraction with JP-8 and Creased at −25 °F, fl oz/ft^2/24 h								
With ASTM Fuel B	F	F	F	F	F	F	F	F
With JP-8	F	F	F	F	F	F	F	F
After Extraction with ASTM Fuel B and Creased at −25 °F, fl oz/ft^2/24 h								
With ASTM Fuel B	F	F	F	F	F	F	F	F
With JP-8	F	F	F	F	F	F	F	F
After Extraction with Diesel Fuel and Creased at −25 °F, fl oz/ft^2/24 h								
With ASTM Fuel B	F	F	F	F	F	F	F	F
With JP-8	F	F	F	F	F	F	F	F

[a] Cracking of coating during crease test at −25 °F

Table 3. Summary of diffusion results for nitrile-coated fabrics (continued).

Fabric Supplier	**Reeves**	**Reeves**	**BLSS**	**AEF**	**AEF**	**Berg**	**Berg**	**GMA Covers**
Fabric Manufacturer	**Reeves**	**Reeves**	**BLSS**	**Archer**	**Reeves**	**Reeves**	**Reeves**	**Musthane**
Fabric Manufacturer Number	**LR071044A**	**18619S**	**—**	**4111**	**LR011096A**	**First Sample**	**Production**	**—**
Fuel Diffusion After Conditioning at 160 °F, fl oz/ft^2/24 h								
As-Received								
With ASTM Fuel B	1.4571	1.2301	0.1945	0.9973	1.3804	1.7836	2.5846	0.3445
With JP-8	0.5654	0.2271	0.0379	0.1487	0.2528	0.4508	0.6668	0.0246
As-Received and After Creased at −25 °F, fl oz/ft^2/24 h								
With ASTM Fuel B	1.9834	1.4198	F[a]	F	1.5510	1.7736	2.7556	2.0164
With JP-8	1.4974	1.2251	F	F	0.2958	1.7003	0.6874	0.0352
Notes:								

[a] Cracking of coating during crease test at −25 °F

3.1.2 Tear Strength, Breaking Strength, Puncture Resistance, and Weight

Tear strength tests on the as-received coated fabric materials were performed per ASTM D 751, Procedure B and are presented in figure 5 and table 4. All of the nitrile-coated fabric materials in this study utilized nylon base fabrics. All nitrile fabrics exhibited higher tear strength in the warp direction. The Reeves LR071044A coated fabric provided the highest tear strength in both warp (218 lb) and fill (145 lb) directions. The fabric currently being used by Berg to build tanks for the military identified as Berg/Reeves Production provided the next highest tear strength properties (149 × 129 lb). The lowest tear strengths were provided by BLSS (74 × 64 lb), AEF/Archer (59 × 61 lb) and Musthane (57 × 57 lb). All of these tear strength properties exceeded the requirements of MIL-T- 52983G tank specification.

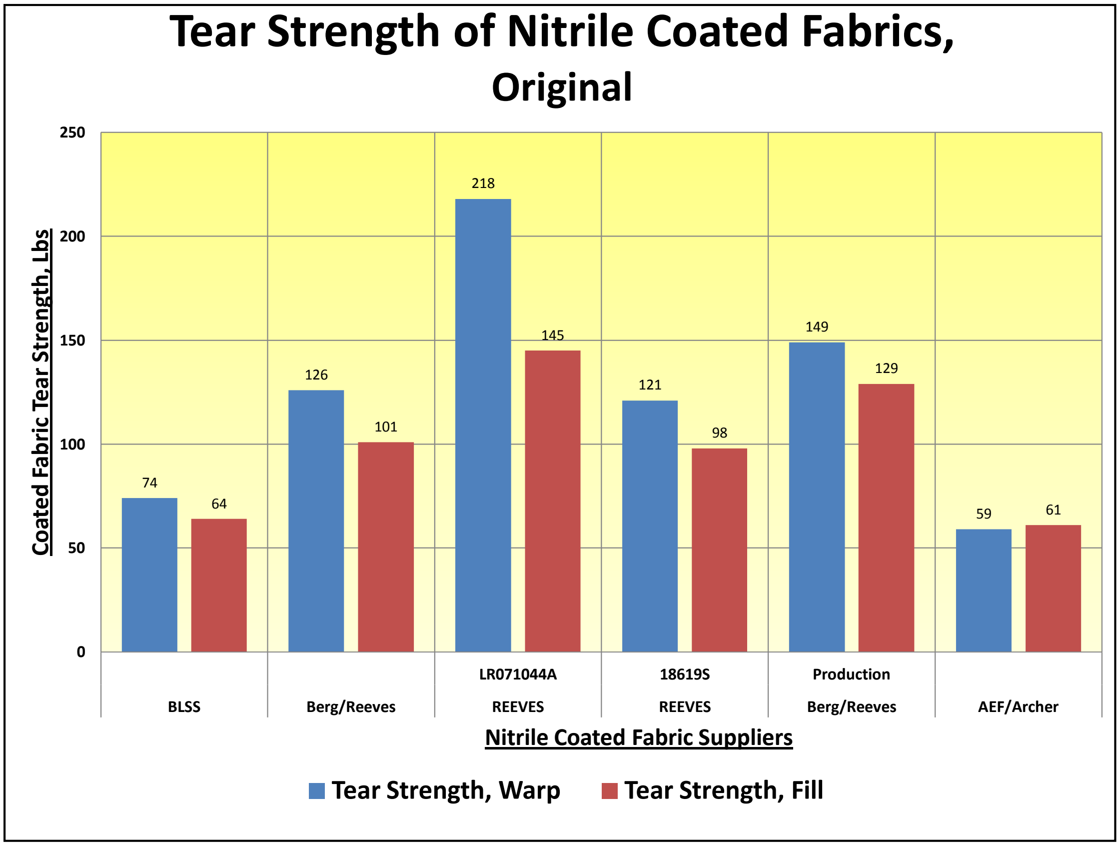

Figure 5. Fabric weights for coated fabrics.

Table 4. Summary of physical properties for nitrile-coated fabrics.

Tank Coated Fabric Supplier	**Reeves**	**Reeves**	**AEF**	**BLSS**	**Dunlop**	**Berg**	**Berg**	**GMA Covers**
Coated Fabric Manufacturer	**Reeves**	**Reeves**	**Archer**	**BLSS**	**Dunlop**	**Reeves**	**Reeves**	**Musthane**
Fabric Manufacturer Number	**LR071044A**	**18619S**	**4111**	**—**	**2008**	**232254021**	**235690-023**	**Musthane**
Base Fabric	Nylon	Nylon	Nylon	Nylon	Nylon	Nylon	Nylon	Nylon
Coating Type	Nitrile	Nitrile	Nitrile	Nitrile	Nitrile	Nitrile	Nitrile	Nitrile
1. Coated Fabric Weight, oz/yd^2	48.8	43.2	43.4	43.9	61.4	53.8	47.6	42.0
2. Tear Strength, Warp, lb	217.8	120.9	59.4	73.9	96.3	126.2	149.2	57.0
3. Tear Strength, Fill, lb	144.5	98.0	60.6	64.1	102.3	101.3	129.2	56.8
4. Breaking Strength, Warp, lb/in	735.9	807.0	680.5	738.7	742.8	741.6	748.8	474.3
5. Breaking Strength, Fill, lb/in	795.9	775.0	672.8	523.7	825.9	686.0	555.6	430.9
6. Puncture Resistance								
a. As-Received, lb	296.3	277.8	209.1	254.5	295.3	267.1	287.2	138.0
b. After JP-8 Extraction and Immersed 28 Days in Water at 180 °F, lb	220.7	209.4	169.4	N/T	N/T	201.3	217.6	136
c. After Accelerated Weathering, lb	272.5	255.3	230.2	252.8	259.2	273.5	283.9	129
d. After Extraction in JP-8 and Accelerated Weathering, lb	262.8	215.4	197.7	284.4	239.4	238.7	265.3	126
7. Weather Resistance, Stretched 5%, Breaking Strength, Warp, lb/in	803.6	758.7	710.7	747.3	754.9	754.4	715.2	461
8. Weather Resistance, Stretched 5%, Breaking Strength, Fill, lb/in	755.7	685.6	666.2	595.8	709.1	686.5	671.1	453
9. Weather Res. After JP-8 Extraction, Stretched 5%, Warp, lb/in	806.0	764.8	658.3	806.4	696.2	739.7	738.7	491
10. Weather Res. After JP-8 Extraction, Stretched 5%, Fill, lb/in	774.7	742.3	632.5	505.5	708.3	626.9	662.6	438

Table 4. Summary of physical properties for nitrile-coated fabrics (continued).

Tank Coated Fabric Supplier	**Reeves**	**Reeves**	**AEF**	**BLSS**	**Dunlop**	**Berg**	**Berg**	**GMA Covers**
Coated Fabric Manufacturer	**Reeves**	**Reeves**	**Archer**	**BLSS**	**Dunlop**	**Reeves**	**Reeves**	**Musthane**
Fabric Manufacturer Number	**LR071044A**	**18619S**	**4111**	**—**	**2008**	**232254021**	**235690-023**	**Musthane**
Base Fabric	**Nylon**	**Nylon**	**Nylon**	**Nylon**	**Nylon**	**Nylon**	**Nylon**	**Nylon**
Coating Type	**Nitrile**	**Nitrile**	**Nitrile**	**Nitrile**	**Nitrile**	**Nitrile**	**Nitrile**	**Nitrile**
1. Blocking, Minutes to Separation								
a. As-Received, Unaged								
1. Inside to Inside	Pass	Pass	Fail (>5 s)	Pass	Pass	Pass	Pass	Pass
2 Outside to Outside	NA	NA	NA	Pass	Pass	NA	NA	Fail
b. After Immersion in Diesel Fuel for 14 Days at 160 °F								
1. Inside to Inside	Pass	Pass	N/T	Pass	Pass	Pass	Fail	N/T
2. Outside to Outside	NA	NA	NA	Pass	Pass	NA	NA	NA
c. After JP-8 Extraction, Water Immersion for 28 Days at 180 °F								
1. Inside to Inside	Pass	Pass	Pass	Pass	Pass	Pass	Pass	NA
2. Outside to Outside	NA	NA	NA	Pass	Pass	NA	NA	NA
d. After Immersion in ASTM Fuel B for 14 Days at 160 °F								
1. Inside to Inside	Pass	Fail	Fail (>5 s)	N/T	N/T	Pass	Pass	Pass
2. Outside to Outside	NA	NA	NA	N/T	N/T	NA	NA	NA
2. Ozone Resistance, Aged at 104 °F and 50 ppm Ozone; 21 Day Test								
a. As-Received, Unaged, Days to First Crack								
1. Inside to Inside	Pass	Fail (12)	Pass	Pass	Fail (1)	Fail	Pass	N/T
2. Outside to Outside	NA	NA	NA	Pass	Fail (1)	N/A	N/A	N/T
b. Ozone Resistance, 14 Days ASTM B at 160 °F, Days to First Crack								
1. Inside Coating	Pass	Pass	Pass	Pass	Fail (1)	Pass	Pass	N/T

Table 4. Summary of physical properties for nitrile-coated fabrics (continued).

Tank Coated Fabric Supplier	**Reeves**	**Reeves**	**AEF**	**BLSS**	**Dunlop**	**Berg**	**Berg**	**GMA Covers**
Coated Fabric Manufacturer	**Reeves**	**Reeves**	**Archer**	**BLSS**	**Dunlop**	**Reeves**	**Reeves**	**Musthane**
Fabric Manufacturer Number	**LR071044A**	**18619S**	**4111**		**2008**	**232254021**	**235690-023**	**Musthane**
Base Fabric	**Nylon**	**Nylon**	**Nylon**	**Nylon**	**Nylon**	**Nylon**	**Nylon**	**Nylon**
Coating Type	**Nitrile**	**Nitrile**	**Nitrile**	**Nitrile**	**Nitrile**	**Nitrile**	**Nitrile**	**Nitrile**
2. Outside Coating	NA	NA	NA	Pass	Fail (1)	NA	NA	N/T
c. Ozone Res. After JP-8 Extraction, Days to First Crack								
1. Inside Coating	Pass	Pass	Pass	Pass	Fail (1)	Pass	Pass	N/T
2. Outside Coating	NA	NA	NA	Pass	Fail (1)	NA	NA	N/T
3. Ozone Resistance, Aged at 121 °F (50 °C) and 50 ppm Ozone								
a. As-Received, Unaged, Days to First Crack								
1. Inside to Inside	Pass	Fail	Pass	Pass	Fail (1)	Fail	Pass	Pass
2. Outside to Outside	NA	NA	NA	Fail	Fail (1)	NA	NA	Pass
b. Ozone Resistance, 14 Days ASTM B at 160 °F, Days to First Crack								
1. Inside Coating	Pass	Pass	Pass	Pass	Fail (1)	Pass	Pass	N/T
2. Outside Coating	NA	NA	NA	Fail	Fail (1)	NA	NA	N/T
c. Ozone Res. After JP-8 Extraction, Days to First Crack								
1. Inside Coating	Pass	Pass	Pass	N/T	Fail (1)	Pass	Pass	N/T
2. Outside Coating	NA	NA	NA	Fail	Fail (1)	NA	NA	N/T
4. Color of Coating								
a. Exterior Coating	Sand	Sand	Tan	Tan	Black	Sand	Sand	Tan
b. Interior Coating	Sand	Sand	Tan	Black	Black	Sand	Sand	Black

Figure 6 presents the fabric weights for each of the nitrile fabrics. The weights varied from 53.5 oz/yd^2 for the Berg/Reeves material to 43.2 oz/yd^2 for the Reeves 18619S nitrile. The fabric weight value can have a dramatic effect on the deployability of the fuel storage tank in theater because the large increase in fabric weight will have a dramatic impact in the total weight of the tank. A current field 210 K storage tank has an approximate area of 1000 yd^2.

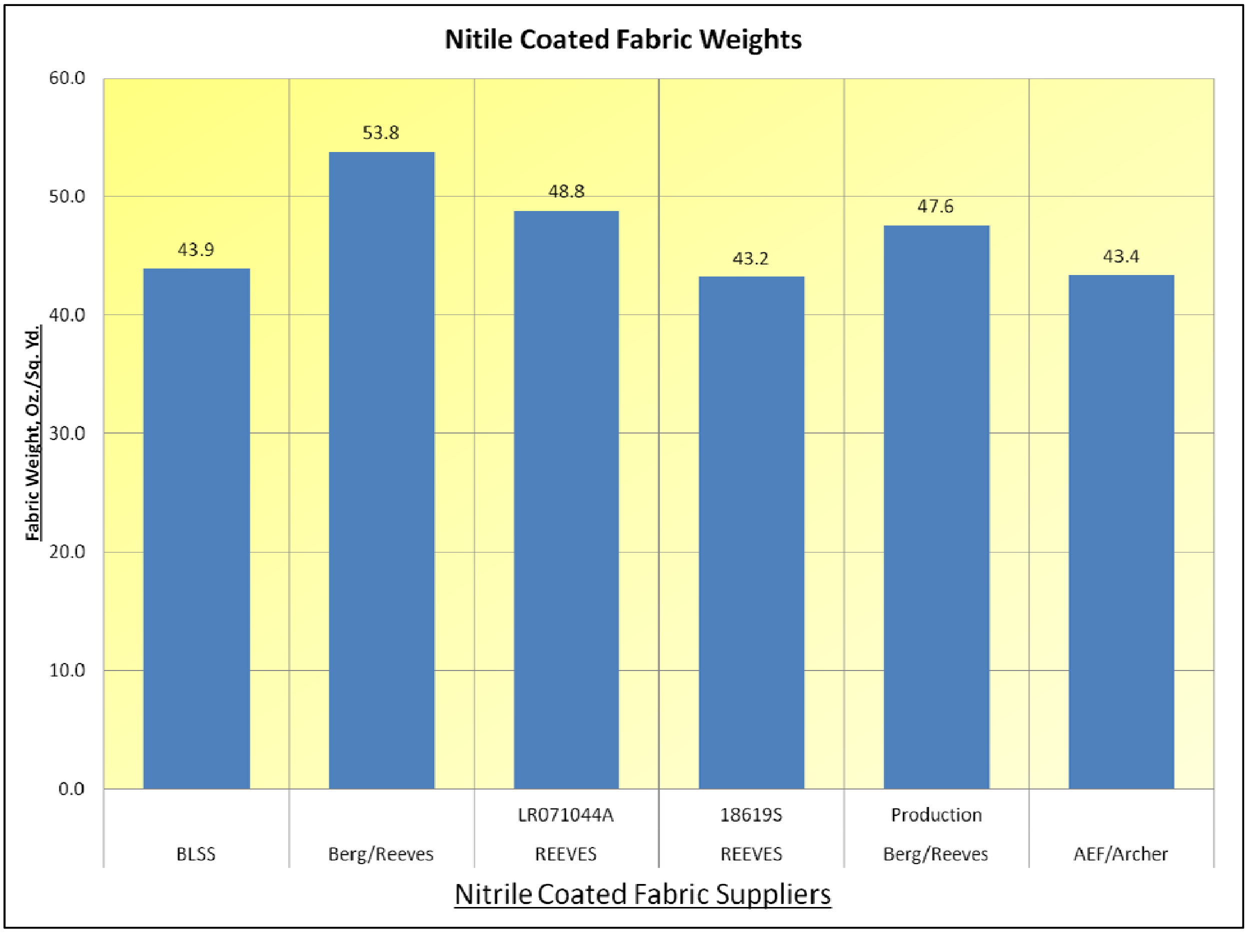

Figure 6. Fabric weights for coated fabrics.

The breaking strength testing results of the base fabrics were performed per ASTM D 751, procedure B and are presented in figure 7 and table 4. All nitrile materials met the military specification requirement (550 lb/in) for tanks ranging in size from 20,000 to 50,000 gal. As expected, strengths in warp direction were larger than those in the fill direction. This is due to the elongation and alignment of the individual nylon fibers during processing. The only surprise was the large difference in breaking strength between the warp and fill direction for the BLSS and the Berg/Reeves production nitriles.

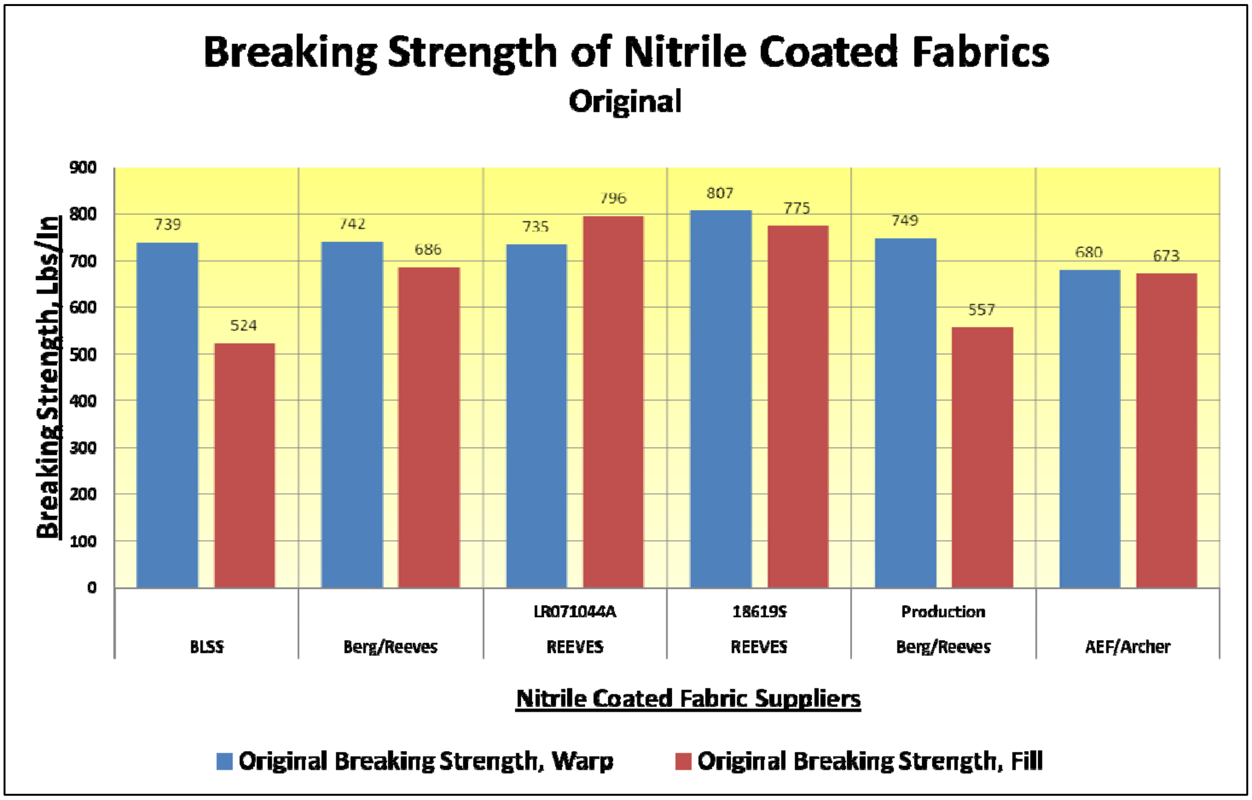

Figure 7. Breaking strengths for as-received coated fabrics. Breaking strengths were performed in both the fill and warp directions.

In figure 8 and table 4, the breaking strength of materials that have been conditioned with accelerated weathering using the Xenon light type light weatherometer are compared to original breaking strengths. All nitrile materials presented in this figure were not significantly affected by accelerated weathering and retained adequate breaking strength after accelerated weathering. The most notable result is the breaking strength in the fill direction for the BLSS and the Berg/Reeves production materials. In both fabrics, the fill strength actually increases significantly after weathering. It is unclear why this is occurs.

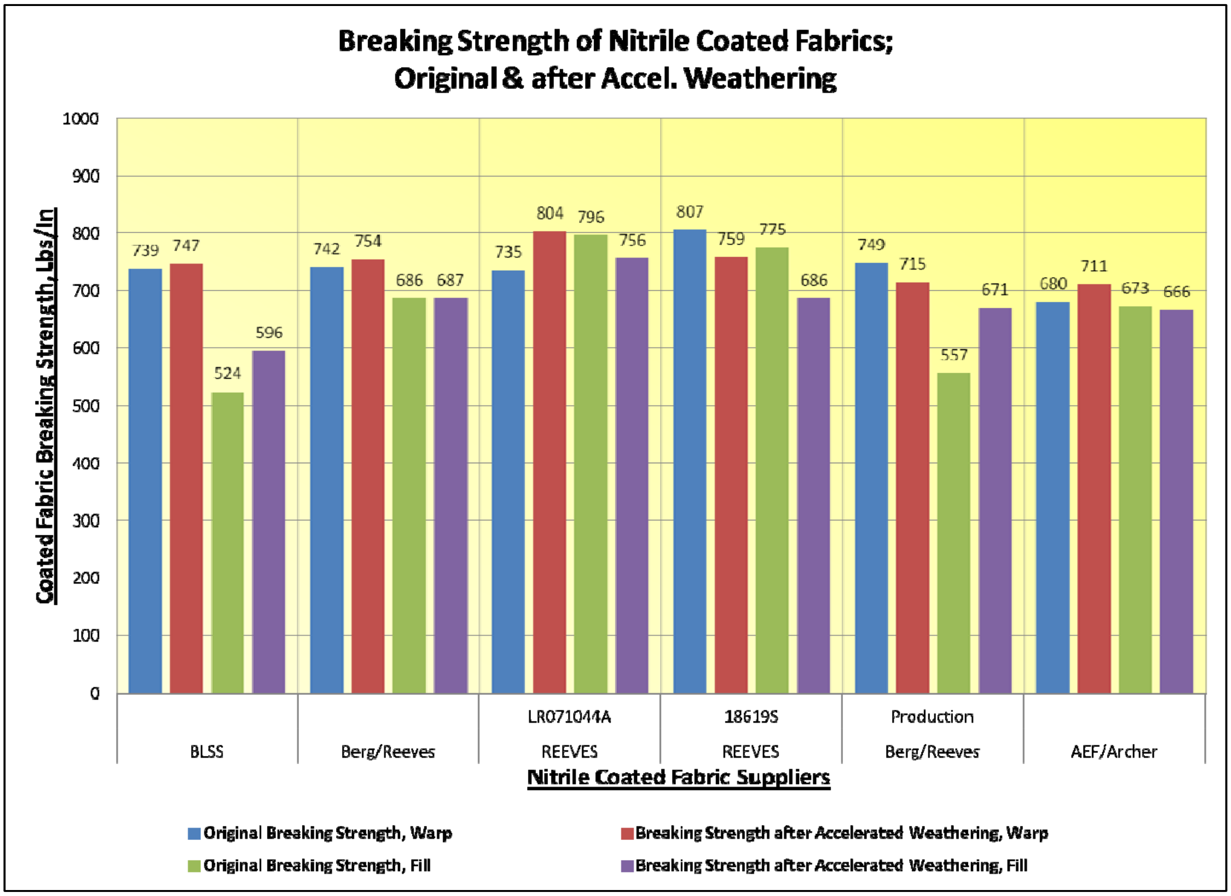

Figure 8. Breaking strengths for coated fabrics after accelerated weathering. Graph compares original and aged coated fabrics. Breaking strengths were performed in both the fill and warp directions.

In figure 9 and table 4, the breaking strength of materials that have been exposed to accelerated weathering after extraction with JP-8 are compared to original breaking strengths. In order to meet the low temperature crease requirement and have the ability to be flexible at low temperatures, nitrile-coated fabric manufacturers incorporate plasticizers into the nitrile coating. A plasticizer is usually an oily type additive that allows the nitrile coating to remain flexible at low temperatures. It is well known that over time, much of this plasticizer will leach out into the fuel. To mimic this effect, a preconditioning step was performed where the coated fabric is immersed in fuel and the coated fabric is then evaluated. All of the materials in this figure were not significantly affected by accelerated weathering and retained adequate breaking strength after accelerated weathering. As seen in the previous graph, the Berg/Reeves production fabric increased in breaking strength after weathering.

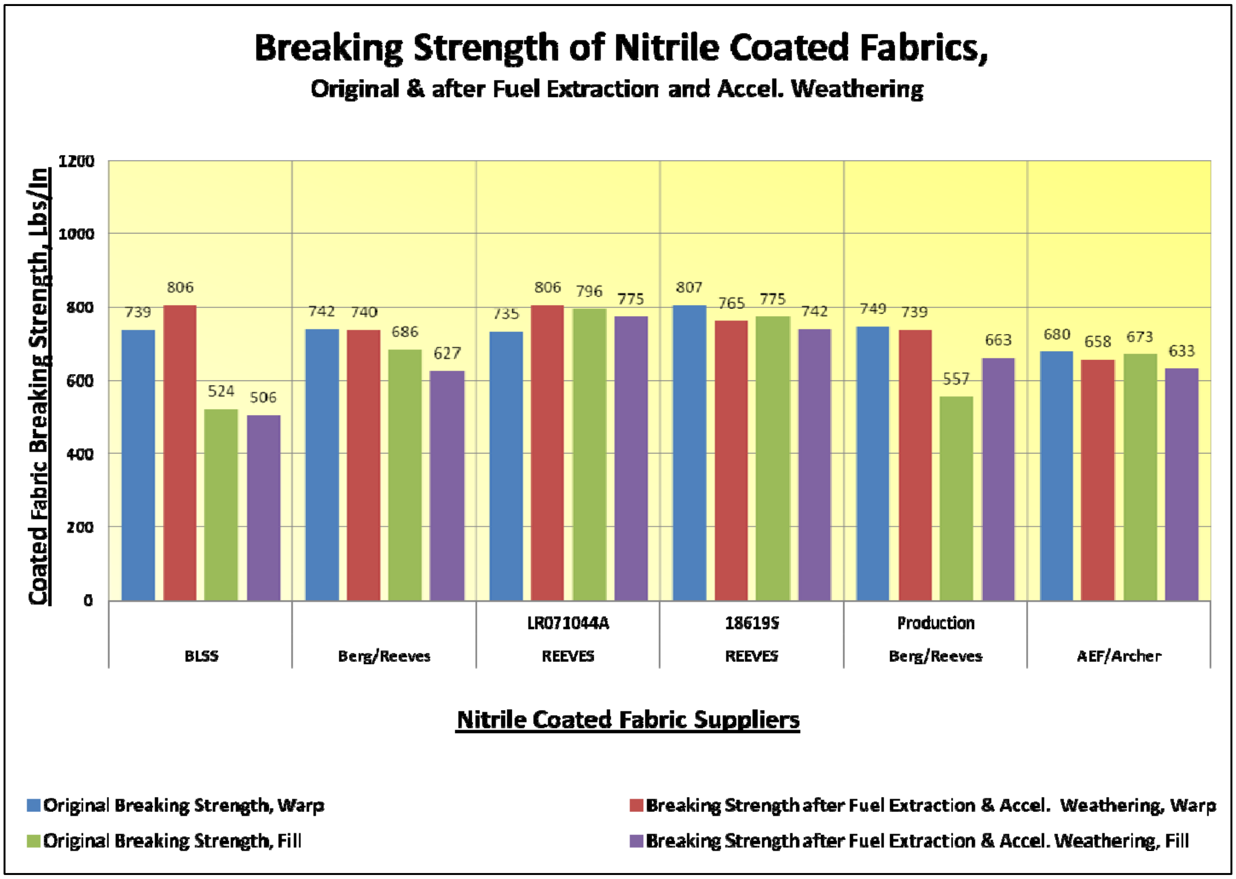

Figure 9. Breaking strengths for coated fabrics after extraction with JP-8 and subsequent accelerated weathering. Breaking strengths were performed in both the fill and warp directions.

A critical property of any coated fabric that holds fuel is that it is highly resistant to puncturing. Figure 10 presents the original puncture resistance anis compared to puncture resistance after accelerated weathering, puncture resistance after fuel extraction followed by accelerated weathering, and puncture after fuel extraction followed by immersion in water for 28 days at 180 °F. The weathering of the various materials, even after the first being fuel extracted, did not adversely affect the puncture resistance of the materials. Most of the materials showed a greater reduction after the materials were fuel extracted than immersed in water for 28 days at 180 °F (5%–25% reduction).

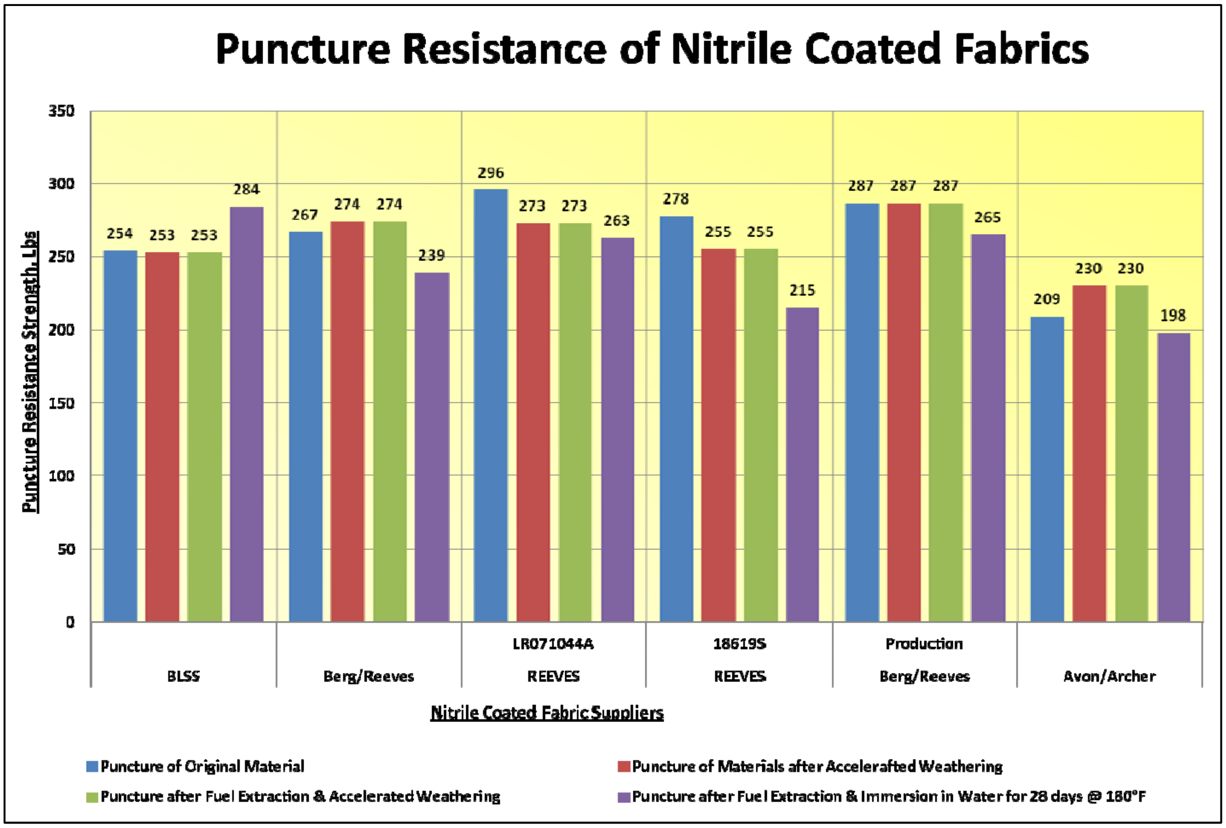

Figure 10. Puncture resistance results for the as-received fabrics and after several conditioning methods.

3.1.3 Torsional Stiffness of Nitrile-Coated Fabric Materials

There is no current requirement for the stiffness of the coated fabric materials used to manufacture tanks. An attempt was made to study the stiffness of candidate coated fabrics as received, after accelerated weathering and after fuel extraction at room temperature, at 32 and –25 °F to get a better idea of the handling properties of these materials when a tank needs to be deployed, especially at low temperatures.

In figure 11and table 5, the torsional stiffness performance on the as-received coated fabric materials are compared at +72, +32, and –25 °F. From figure 11, all of the materials displayed similar low stiffness values at +72 and +32 °F, but at –25 °F, the BLSS and AEF/Archer materials were 10 to 20 times stiffer than the other nitrile materials. This increase in stiffness is likely due to the lack of plasticizer blended into the nitrile coating. Tanks made from these three materials would be harder to deploy at low temperatures.

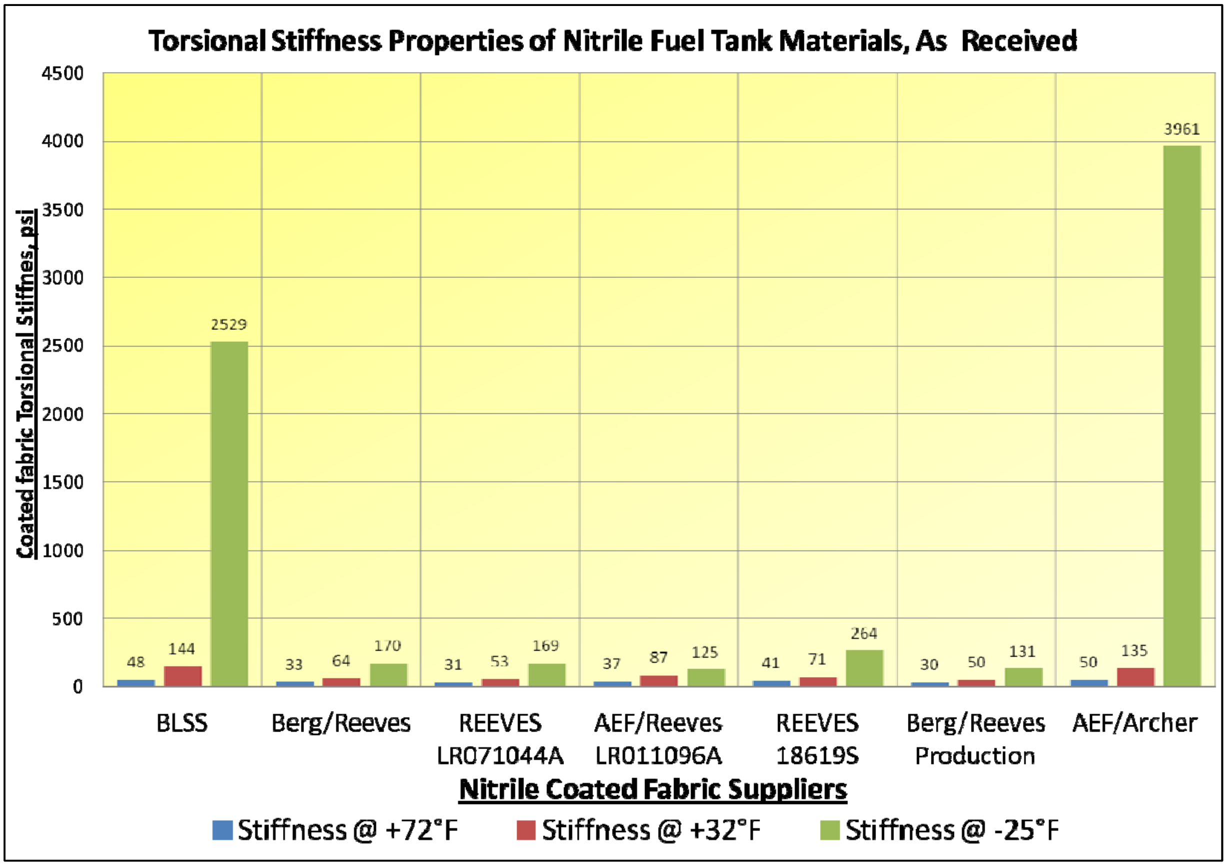

Figure 11. Torsional stiffness results for as-received coated fabrics at three temperatures.

Table 5. Summary of torsional stiffness results for nitrile-coated fabrics taken at various temperatures.

		As-Received Materials		**As-Received Materials**		**Extracted with JP-8 Fuel**		**After Accelerated Weathering**	
		DMA Properties		**Torsional Properties**		**Torsional Properties**		**Torsional Properties**	
Material ID	**Temperature**	**E'**	**E"**	**Torsional**	**Youngs**	**Torsional**	**Youngs**	**Torsional**	**Youngs**
				Stiffness	**Modulus**	**Stiffness**	**Modulus**	**Stiffness**	**Modulus**
	°C	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**
Pronal USA	−31.7	50,763	10,196	669	2,007	3,251	9,753	2,648	7,944
	0	6,034	1,037	129	387	345	1,035	212	636
	22	4,067	426	44	132	95	285	76	228
Pronal France	−31.7	55,985	9,079	273	819	3,438	10,314	1,849	5,547
	0	3,101	926	132	396	263	789	174	522
	22	1,238	176	56	168	76	228	65	195
Dunlop	−31.7	107,038	16,534	59	177	4,341	13,023	160	480
	0	7,643	1,639	60	180	123	369	97	291
	22	4,279	624	30	90	45	135	43	129
									0
AMFUEL	−31.7	10,443	5,511	239	717	728	2,184	2,300	6,900
	0	1,798	189	117	351	116	348	486	1,458
	22	1,856	106	54	162	50	150	185	555

Table 5. Summary of torsional stiffness results for nitrile-coated fabrics taken at various temperatures (continued).

		As-Received Materials		As-Received Materials		Extracted with JP-8 Fuel		After Accelerated Weathering	
		DMA Properties		**Torsional Properties**		**Torsional Properties**		**Torsional Properties**	
Material ID	**Temperature**	**E'**	**E"**	**Torsional**	**Young's**	**Torsional**	**Young's**	**Torsional**	**Young's**
				Stiffness	**Modulus**	**Stiffness**	**Modulus**	**Stiffness**	**Modulus**
	°C	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**
Zodiac	−31.7	40,466	2,582	7,655	22,965	6,460	19,380	5,017	15,051
	0	2,234	783	389	1,167	281	843	369	1,107
	22	957	113	174	522	108	324	119	357
Engineered Fabrics	−31.7	71,649	62,946	161	483	135	405	1,666	4,998
	0	20,160	2,930	58	174	65	195	339	1,017
	22	12,981	1,574	37	111	41	123	147	441
BLSS (Nitrile)	−31.7	49,893	4,409	2,529	7,587	3,201	9,603	3,321	9,963
	0	4,989	2,010	144	432	363	1,089	229	687
	22	2,234	296	48	144	88	264	80	240
Reeves LR071044A (Nitrile)	−31.7	N/T	N/T	169	507	1,360	4,080	1,235	3,705
	0	N/T	N/T	53	159	151	453	168	504
	22	N/T	N/T	31	93	55	165	116	348
Reeves 18619S (Nitrile)	−31.7	15,229	7,165	264	792	1,349	4,047	1,841	5,523
	0	2,132	348	71	213	161	483	539	1,617
	22	1,813	229	41	123	63	189	283	849

Table 5. Summary of torsional stiffness results for nitrile-coated fabrics taken at various temperatures (continued).

		As Received Materials		As Received Materials		Extracted with JP-8 Fuel		After Accelerated Weathering	
		DMA Properties		Torsional Properties		Torsional Properties		Torsional Properties	
Material ID	**Temperature**	**E'**	**E"**	**Torsional**	**Young's**	**Torsional**	**Young's**	**Torsional**	**Young's**
				Stiffness	**Modulus**	**Stiffness**	**Modulus**	**Stiffness**	**Modulus**
	°C	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**
Avon/Reeves LR011096A (Nitrile)	−31.7	17,695	7,536	125	375	1,530	4,590	1,621	4,863
	0	3,002	354	87	261	152	456	474	1,422
	22	1,664	155	37	111	26	78	174	522
Avon/Archer 4111 (Nitrile)	−31.7	49,458	2,820	3,961	11,883	2,272	6,816	1,895	5,685
	0	2,103	1,171	135	405	198	594	198	594
	22	983	93	50	150	77	231	59	177
Berg/Reeves (Nitrile)	−31.7	29,443	11,993	170	510	1,982	5,946	1,591	4,773
	0	8,050	932	64	192	171	513	274	822
	22	6,034	582	33	99	183	549	102	306
BERG/Reeves Production	−31.7	N/T	N/T	131	393	1,270	3,810	1,867	5,601
	0	N/T	N/T	50	150	139	417	532	1,596
	22	N/T	N/T	30	90	42	126	190	570
			N/T						

In figure 12, the torsional stiffness of the as-received coated fabric materials at –25 °F are compared to the stiffness after fuel extraction and after accelerated weathering. The stiffness for the BLSS material increased slightly after both fuel extraction with JP-8 and after accelerated weathering. This is consistent with the results in figure 11 that the BLSS-coated fabric lacked a plasticizing agent, hence a larger initial stiffness, as well as a modest increase in stiffness after conditioning. The Avon/Archer material experienced a significant reduction in stiffness after being extracted and after accelerated weathering. The reason for this result is unclear. The remaining materials exhibited a minimum six-fold increase in stiffness after extraction and weathering due to the extraction of plasticizer. These nitrile tanks would be hard to deploy where low temperatures would be encountered. The fuel tanks that have been placed in long-term storage would likely be damaged if deployed at –25 °F due to the aging process.

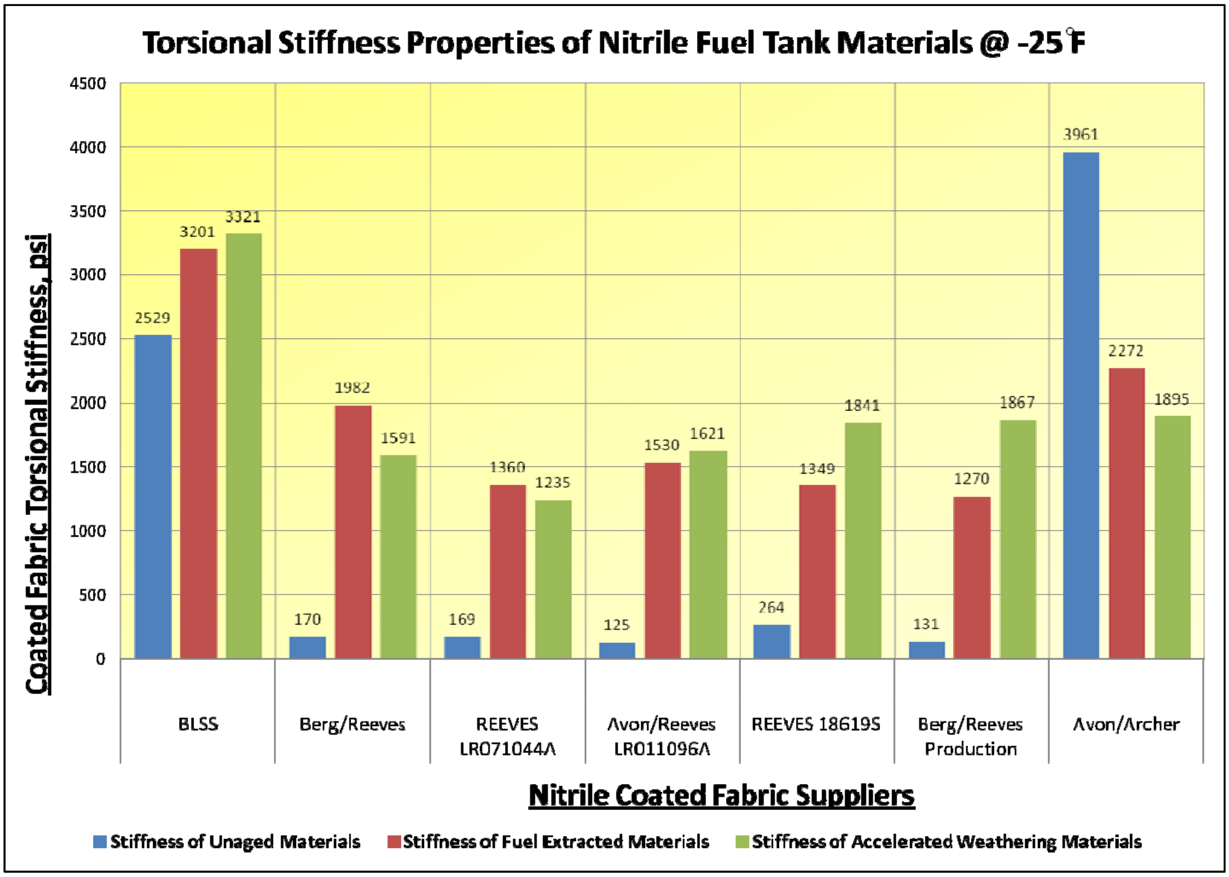

Figure 12. Comparison of the torsional stiffness properties for as-received, fuel extracted, and aged coated fabrics. Experiments were performed at –25 °F.

3.2 Coated Fabric Seam Properties

3.2.1 Breaking Strength of Coated Fabric Seams

In the previous section, the physical, chemical, and mechanical properties of the base coated fabric were reported. These properties are solely based on coated fabric manufactures and not the fuel tank manufacturers. In this section, the properties the coated fabric seams are presented. The seams are created by the fuel tank manufacturer and can be welded in any number of ways. For urethane storage tanks, welded methods may include hot air welding, RF welding, and heated plates. All these seams use the melting of the urethane to adhere one fabric panel to another (*9*).

Nitrile-coated fabrics are inherently different from urethanes in that the nitrile is a thermoset, and, therefore, will not melt at elevated temperatures. The nitrile seaming process requires the use of uncured nitrile rubber in the bond line, which is then thermally cured (*10*).

The breaking strengths of as-received seams at ambient temperature and at 200 °F are presented in figure 13. All fabrics exhibited a similar decreasing trend in breaking strength when evaluated at elevated temperature. All fabrics retained between 70% to 80% of its initial breaking strength. The Berg/Reeves first seam provided the lowest breaking strength at ambient temperature (520.2 lb/in) and at 200 °F (390 lb/in) and neither breaking strength met the minimum MIL-T-52983G requirement of 550 lb/in for the 20 K and 50 K gal tanks. The breaking strengths at room temperature of all the other materials met the specification requirements, but only the AEF/Archer and Dunlop seam materials exceeded 550 lb/in breaking strength at the 200 °F requirement.

The Berg/Reeves first seams were materials generated during the first production run and were not considered high quality. The Berg/Reeves second seams were produced after a significant processing improvement was implemented.

Figure 14 shows the effect of ASTM reference fuel B on the seam breaking strength. The breaking strengths were measured before and after conditioning in ASTM reference fuel B for 14 days at 160 °F and subsequently tested at room temperature and at 200 °F. No decrease in the seam breaking strengths was observed when tested at room temperature. When the temperature was elevated at 200 °F, the Berg/Reeves (second or production) material breaking strength dropped significantly, exhibiting a 45% drop in strength. The Dunlop seam showed only a modest 18% decrease in strength.

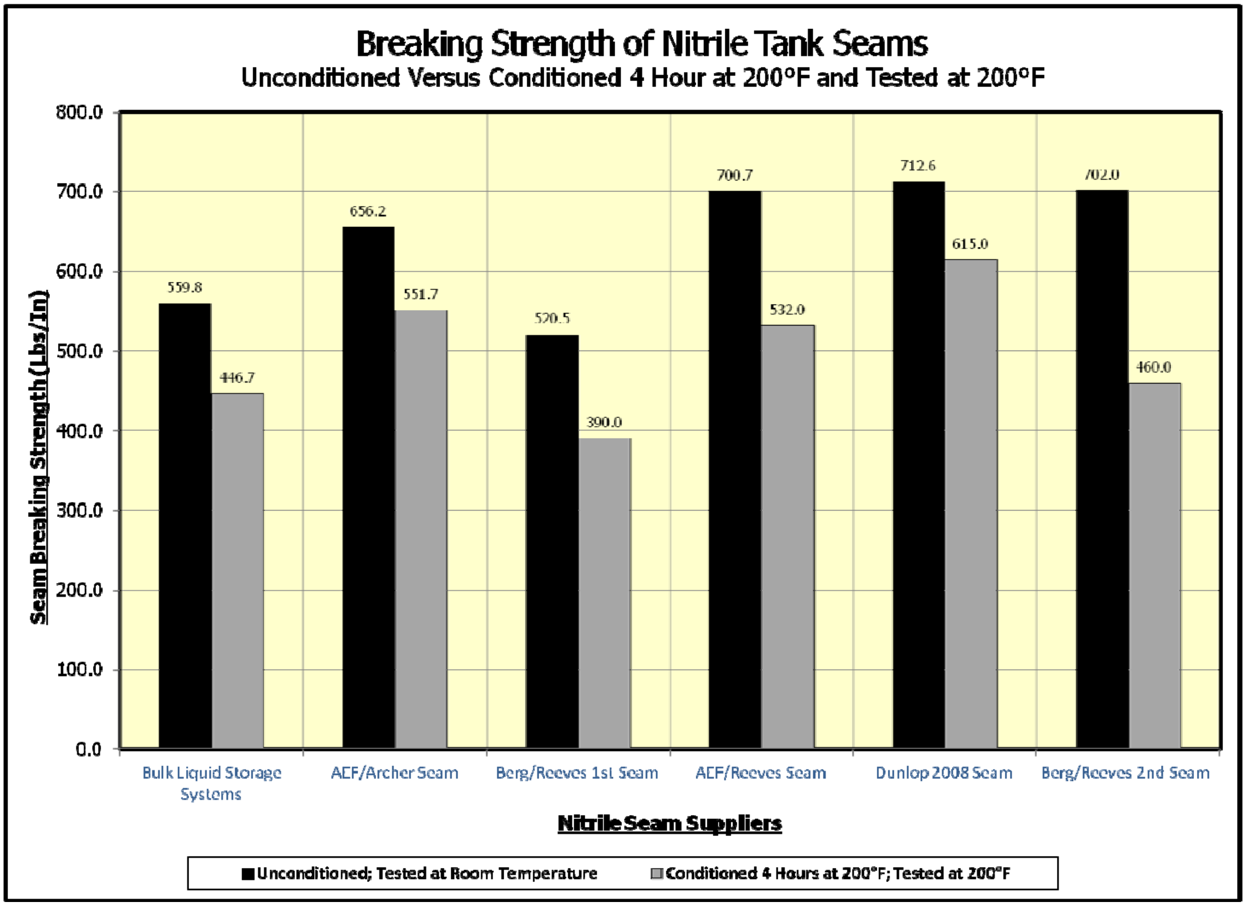

Figure 13. Breaking strengths for nitrile-coated fabric seams unconditioned and thermally conditioned at 200 °F for 4 h. Unconditioned samples tested at room temperature and conditioned samples at 200 °F.

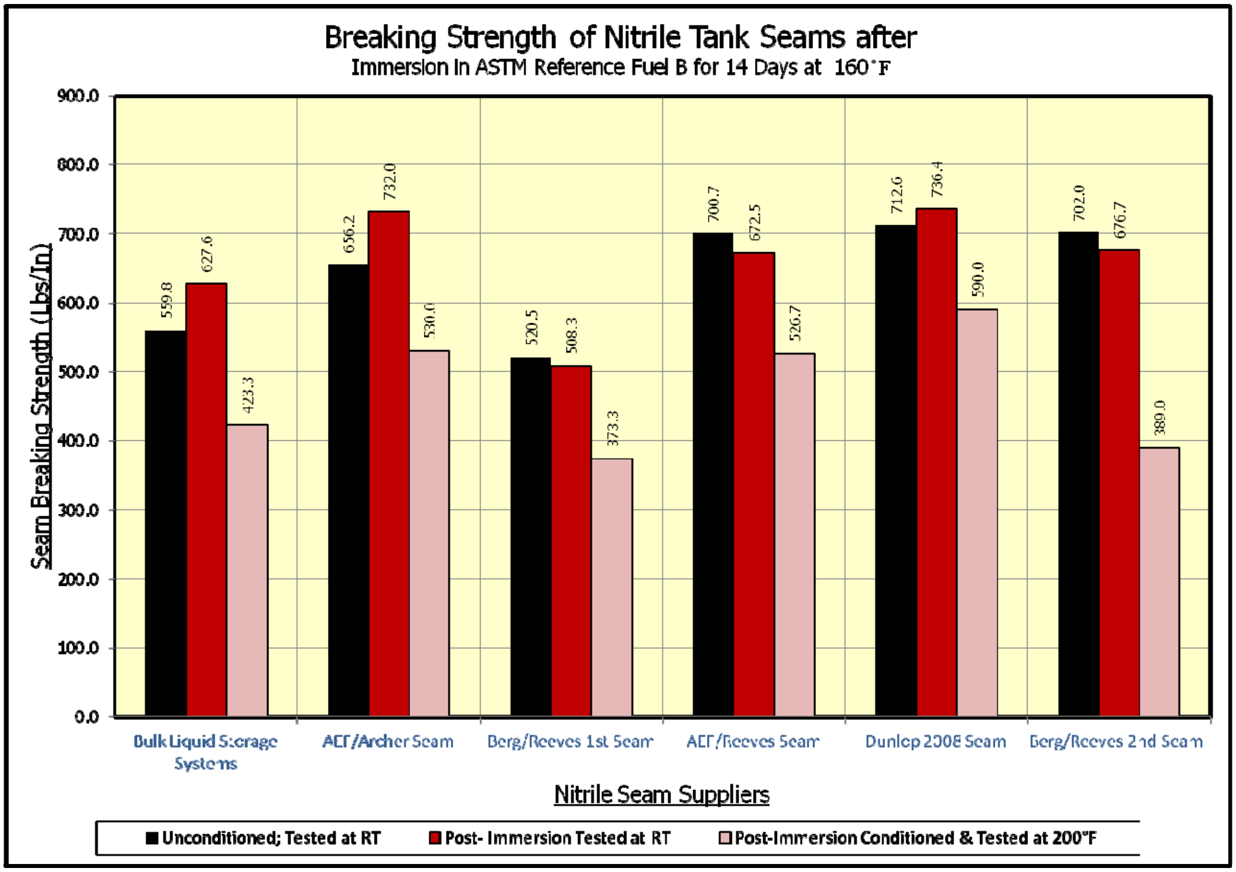

Figure 14. Breaking strengths for nitrile-coated fabric seams unconditioned and after conditioning in ASTM fuel B for 14 days. Specimens were tested at room temperature and at 160 °F.

Figure 15 presents the seam breaking strengths after conditioning in diesel fuel for 14 days at 160 °F and then tested at room temperature and 200 °F. These are compared with breaking strength of seams that have not been conditioned. Surprisingly, the ambient temperature results show an improvement in seam breaking strength for all nitrile-coated fabrics when conditioned with the ASTM fuel. When the experiment is carried out at 200 °F, the Berg/Reeves (second or production) material seam breaking strength dropped the most (40% drop) whereas the Dunlop seam the dropped the least (14% drop).

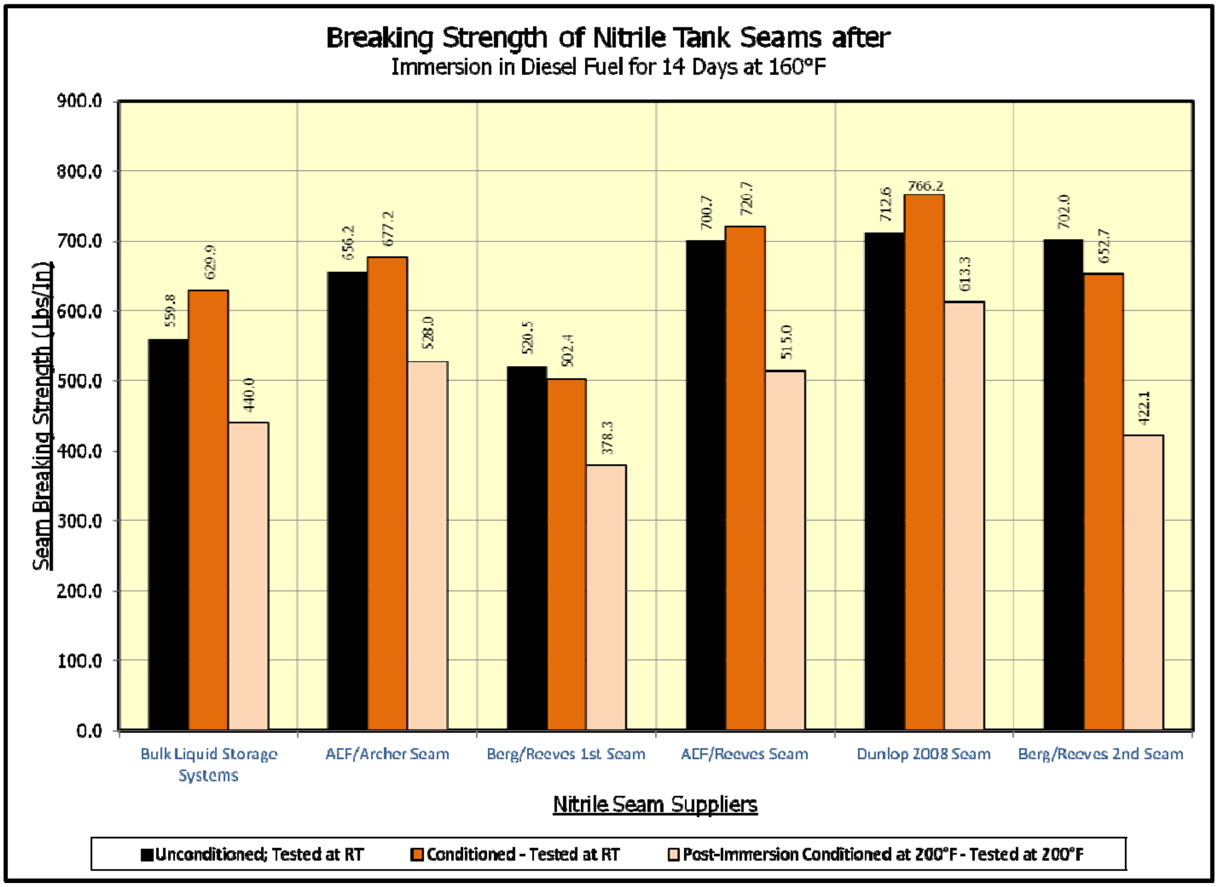

Figure 15. Breaking strengths for nitrile-coated fabric seams unconditioned and after conditioning in diesel fuel for 14 days. Specimens were tested at room temperature and at 200 °F.

In figure 16 the breaking strengths of various coated fabric seams are compared after immersion in diesel fuel and after immersion in ASTM reference fuel B for 14 days at 160 °F. The fabrics were then tested at room temperature. No meaningful differences in material seam breaking strengths were observed for any of the nitrile fabrics studied. The breaking strengths of all the seams met the minimum MIL-T-52983G spec requirement of 400 lb/in when tested at room temperature. However, when the same materials are tested at 200 °F as shown in figure 17, all the seam breaking strengths were reduced about 25% with the exception of the Berg/Reeves production seam, which dropped about 44% for both fuels. Both fuels have an equal effect on the fabric, causing a 20% reduction in breaking strength when tested at 200 °F. All seams retained sufficient breaking strength properties after conditioning in each fuel to pass specification requirements.

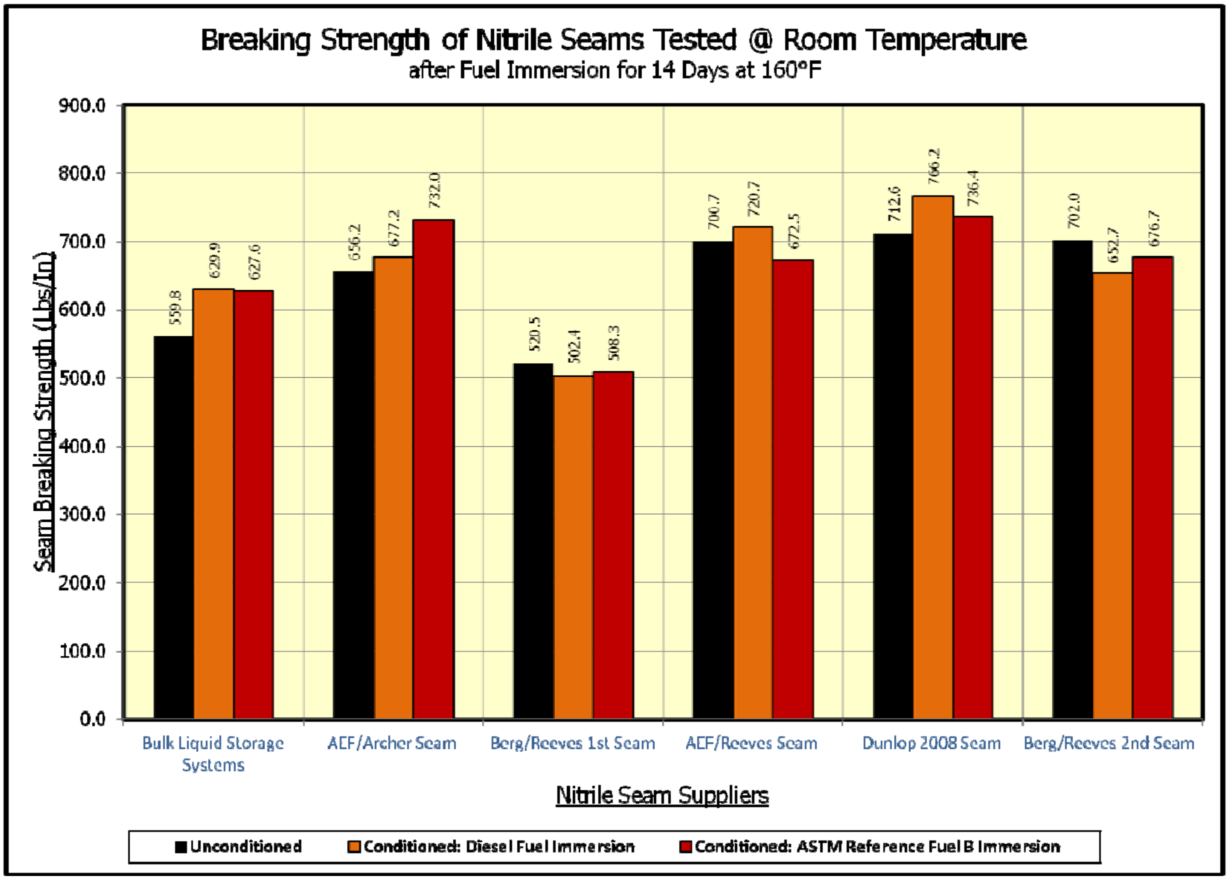

Figure 16. Comparison of breaking strengths for nitrile-coated fabric seams unconditioned and after conditioning in diesel fuel and ASTM fuel at 160 °F for 14 days. Specimens were tested at room temperature.

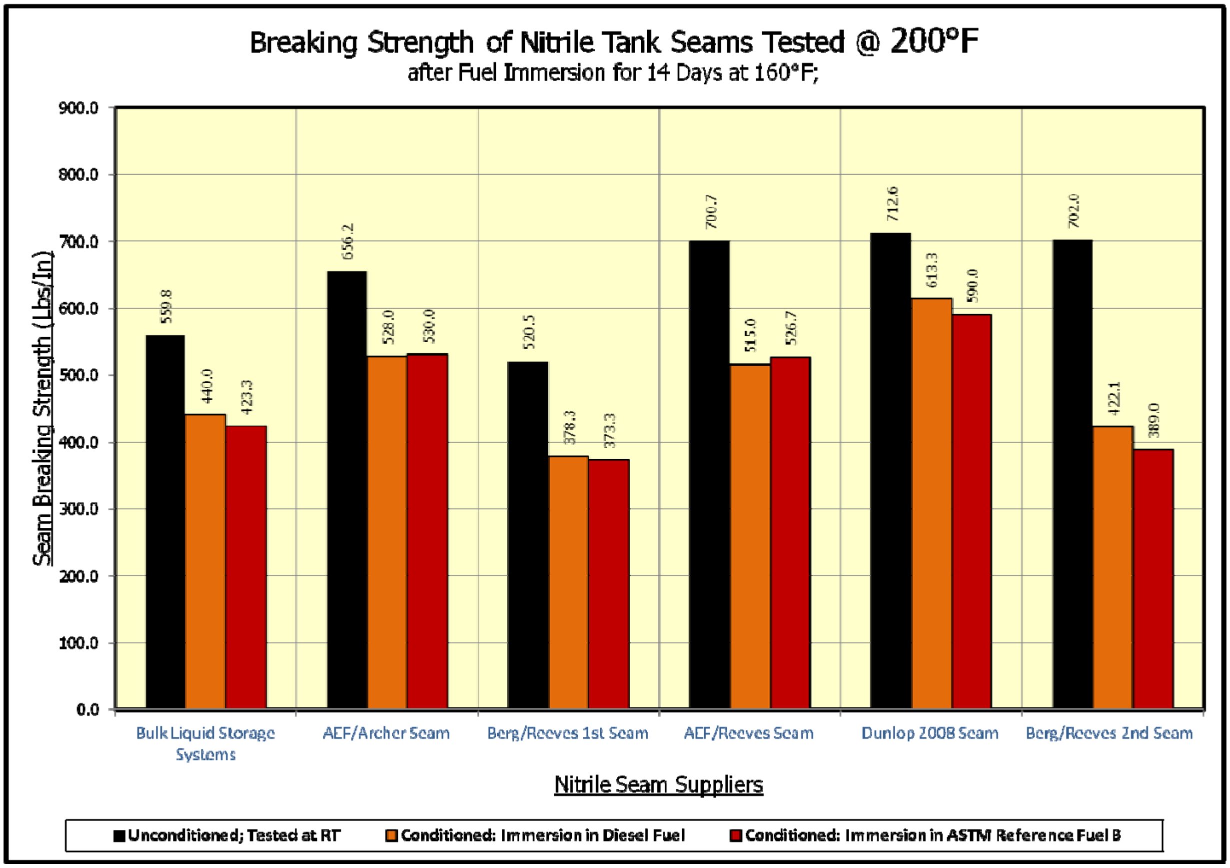

Figure 17. Comparison of breaking strengths for nitrile-coated fabric seams unconditioned and after conditioning in diesel fuel and ASTM fuel at 160 °F for 14 days. Specimens were tested at 200 °F.

Figure 18 shows the effect conditioning the fabrics in water held at 180 °F on the seam breaking strengths. All samples were measured at room temperature. Samples were conditioned at 180 °F in water for time increments of 28, 42, and 70 days. This experiment was performed to assess the ability of nitrile-coated fabric to resist hydrolytic degradation that is common in urethane-coated fabrics. Some fabrics show a sequential decrease in strength (BLSS, AEF/Archer, AEF/Reeves) whereas the remaining fabrics show an initial decrease and a subsequent leveling-off effect. All fabrics demonstrated sufficient breaking strengths to pass specifications.

In figure 19, the seam breaking strengths measured at 200 °F after water immersion at 180 °F for time increments of 28, 42, and 70 days are compared. This graph is the same as figure 18, except that the testing temperature is increased to 200 °F. All fabrics show an initial decrease in breaking strength and a subsequent leveling-off effect. The breaking strength remained consistent at about 67% to 75% strength retention for all fabrics. A minimum value of 345 lb/in was observed regardless of exposure time. A thin layer of clear barrier film on the BLSS material delaminated from the interior black coatings during all water aging tests.

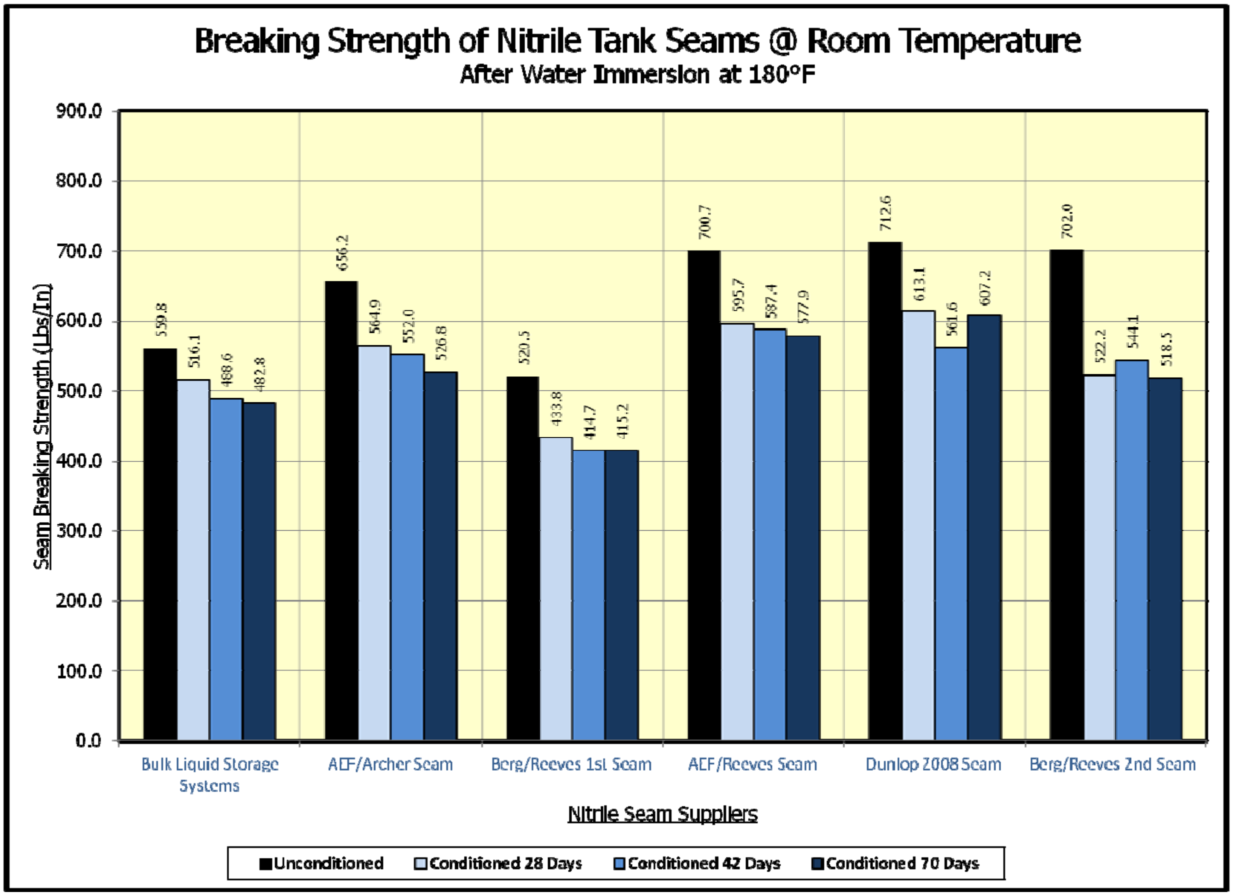

Figure 18. Breaking strengths of nitrile-coated fabric seams after conditioning in water at 180 °F for 28, 42, and 70 days. Specimens were tested at room temperature.

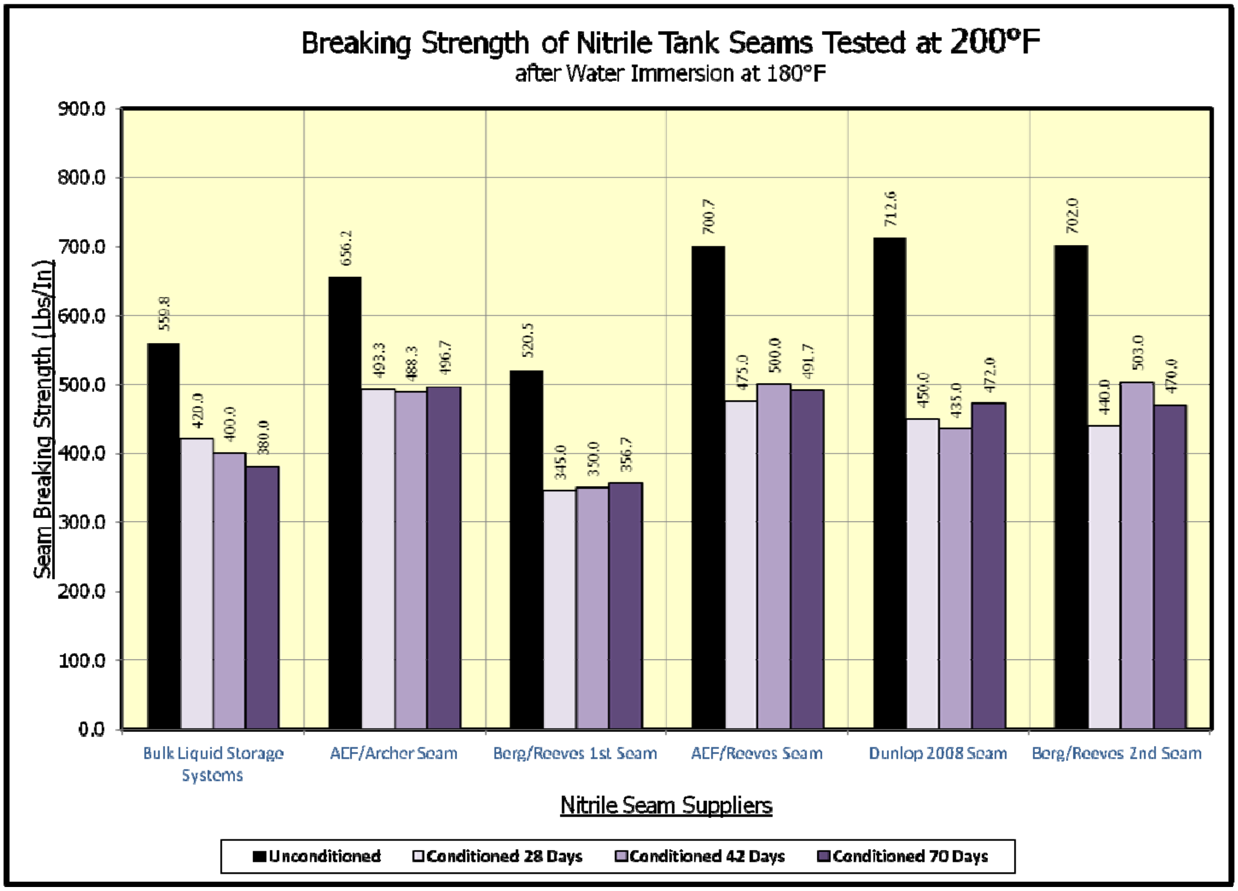

Figure 19. Breaking strengths of nitrile-coated fabric seams after conditioning in water at 180 °F for 28, 42, and 70 days. Specimens were tested at 200 °F.

Figures 20 and 21 present the seam breaking strengths after extraction with JP-8 followed by water immersion at 180 °F for time intervals of 28, 42, and 70 days, measured at room temperature and at 200 °F, respectively. At room temperature, this conditioning had no significant impact on the breaking strength of the BLSS and the AEL/Archer materials. A small difference is observed in the Berg/Reeves first seam. However, a more significant decrease is observed for the Dunlop, AEF/Reeves, and Berg/Reeves second seams. This decrease scales with the exposure time in water. For fabrics evaluated at 200 °F, a more dramatic effect is seen. All materials show a significant decrease in strength that levels off over time. The decrease in strength values measured was between 60%–70% retention of initial strength.

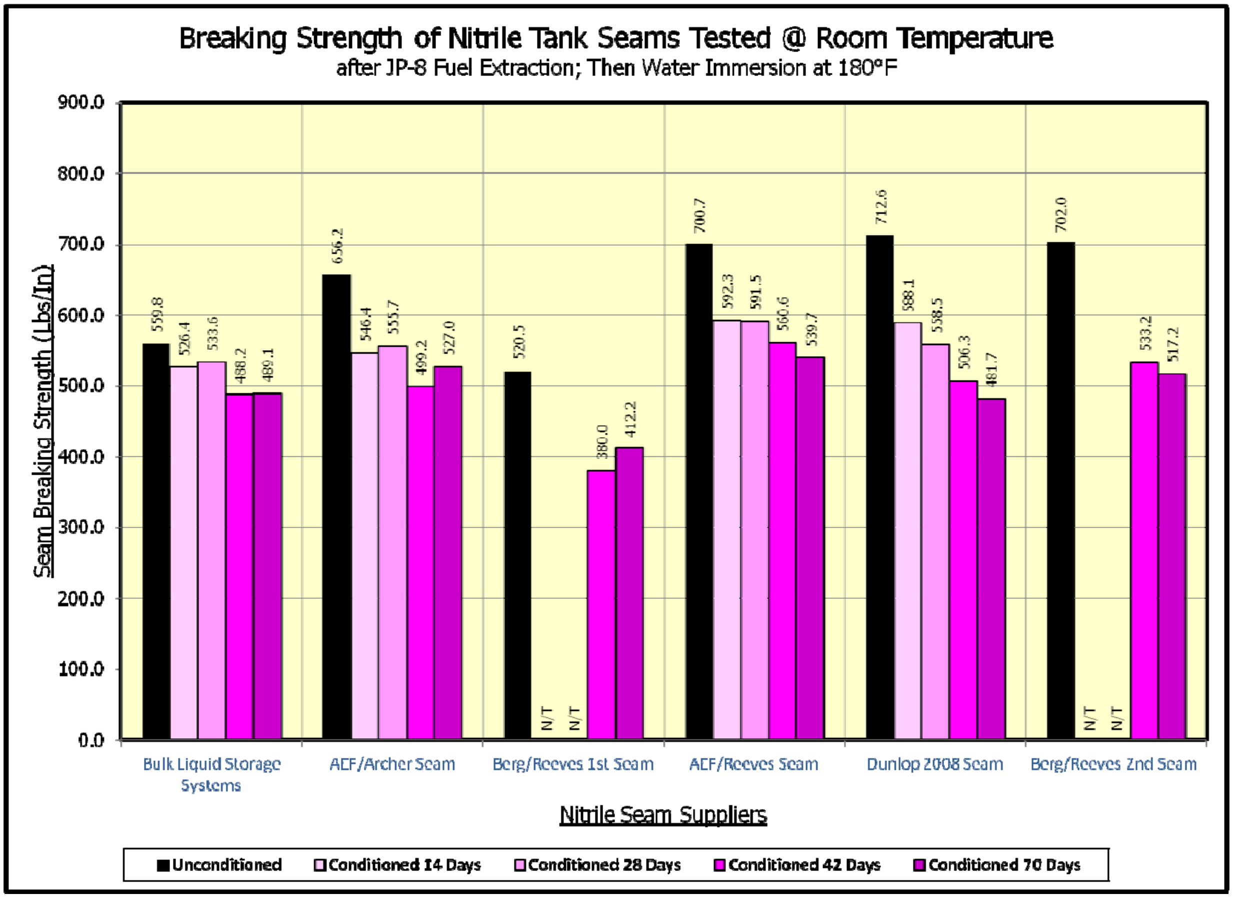

Figure 20. Breaking strengths of nitrile-coated fabric seams after extraction in JP-8 and subsequent conditioning in water at 180 °F for 14, 28, 42, and 70 days. Specimens were tested at room temperature.

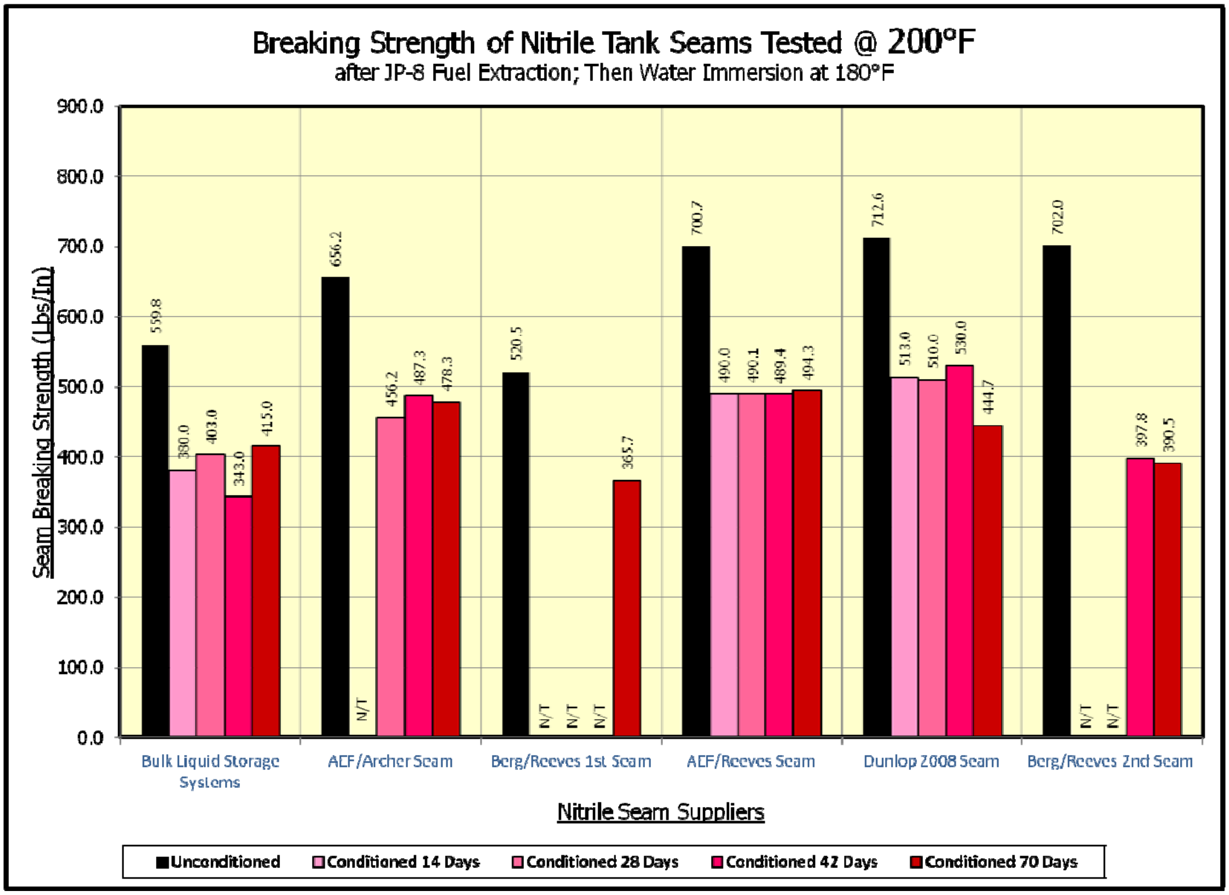

Figure 21. Breaking strengths of nitrile-coated fabric seams after extraction in JP-8 and subsequent conditioning in water at 180 °F for 14, 28, 42, and 70 days. Specimens were tested at 200 °F.

3.2.2 Peel Adhesion of Coated Fabric Seams

The ASTM The peel adhesion of as received seams performed per ASTM D 413, Machine Method at room temperature and at 200 °F are presented in figure 22. The peel adhesion of all the seam materials were dramatically lower (18%–50% retention) when tested at 200 °F compared to their room temperature values. These conditions were chosen to mimic fielded storage tanks in a desert environment. The AEF/Archer seam dropped from 122 to 22 lb/in while the AEF/Reeves seam exhibited very high strength retention (72–37 lb/in). The seams tested at room temperature all passed the MIL-T-52983G minimum requirement of 30 lb/in, whereas the AEF/Reeves seam remained above 30 lb/in when tested at 200 °F. The lowest peel adhesion results when tested at 200 °F were obtained on the BLSS and Berg/Reeves first seams (about 11.8 lb/in). Loss of peel adhesion is likely a result of coating softening at elevated temperatures.

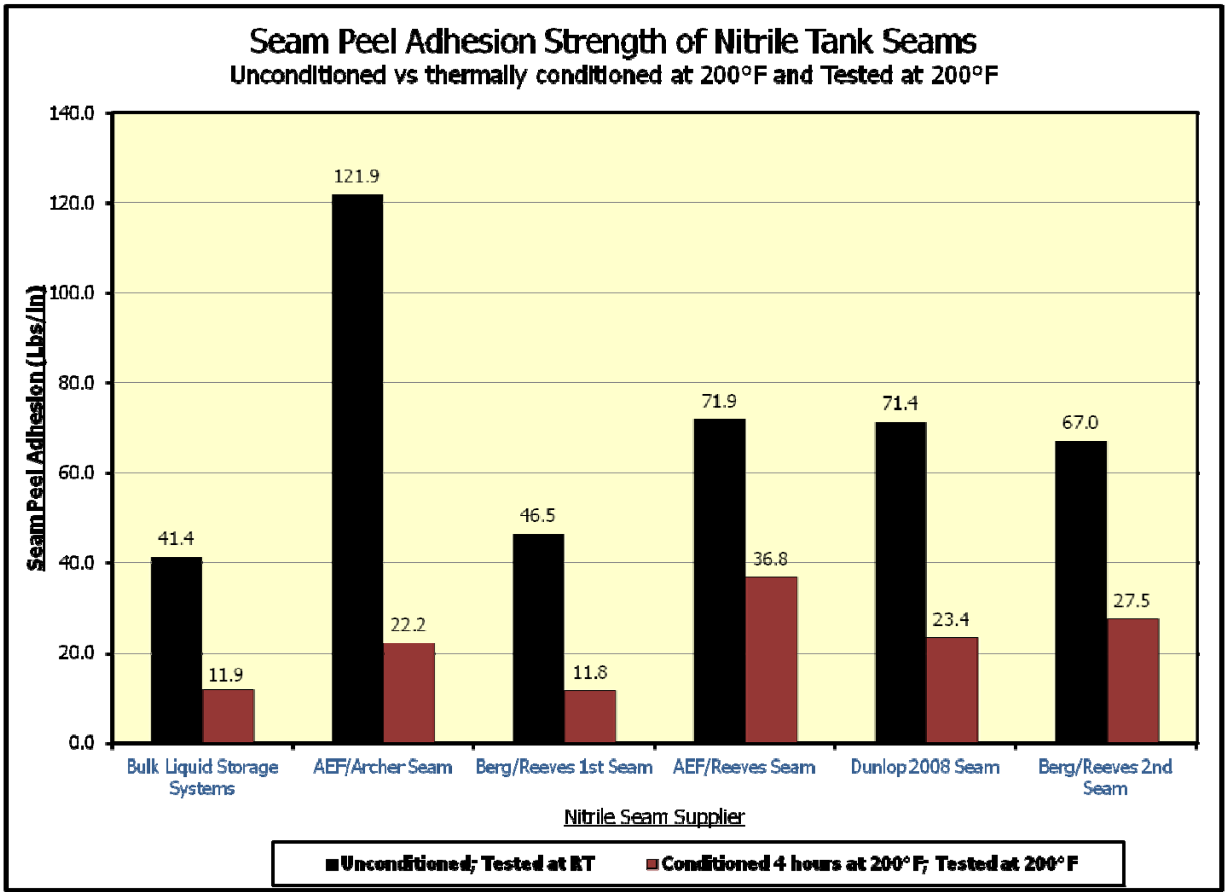

Figure 22. Peel adhesion results for as received and thermally conditioned at 200 °F nitrile-coated fabrics. As-received samples were tested at room temperature and conditioned samples tested at 200 °F.

Figure 23 presents a comparison of the seam peel adhesion strengths of nitrile fabrics after conditioning in diesel fuel and ASTM reference fuel B for 14 days at 160 °F with fabrics that have not been conditioned. Generally, exposure to diesel fuel had a modest effect on the peel strengths. However, in all cases, ASTM fuel B had a more severe effect on the peel adhesion strengths. The AEF/Archer fabric exhibited the largest decrease in strength, retaining only 33% of its original strength. For all nitrile fabrics, the adhesion values were well above the MIL-T-52983G requirement of 20 lb/in and even surpassed the initial requirement of 30 lb/in except for the BLSS seam, which fell to 26.4 lb/in. This result suggests that long-term storage of MoGas in nitrile-coated fabric fuel tanks may not be feasible.

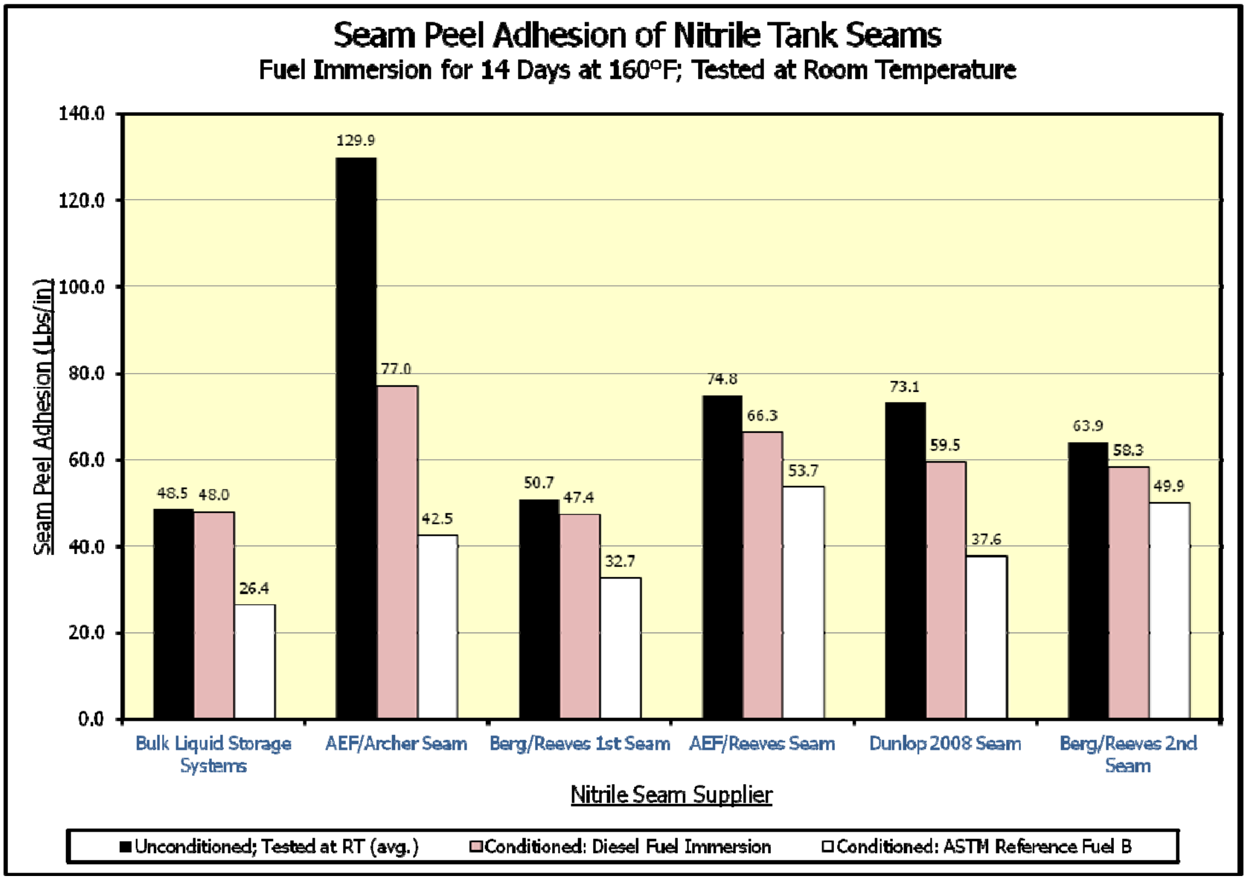

Figure 23. Comparison of peel adhesions for nitrile-coated fabric seams unconditioned and after conditioning in diesel fuel and ASTM fuel at 160 °F for 14 days. Specimens were tested at room temperature.

This effect is even more dramatic when the test is performed at elevated temperatures. In figure 24, the seam peel adhesion after immersion in diesel fuel and ASTM fuel B for 14 days at 160 °F and tested at 200 °F are compared with the peel adhesion of seams of those that have not been immersed and tested at room temperature. The peel adhesions after immersion in the two fuels, for all nitrile fabrics, were dramatically reduced when tested at 200 °F. The BLSS, AEF/Archer, Berg/Reeves first, and Dunlop seams retained less than 20 lb/in peel strength when tested at 200 °F whereas the other two seams retained over 30 lb/in at 200 °F, which exceeds the MIL-T-52983G requirement for initial peel adhesion tested at room temperature. These peel adhesion reductions are due to test temperature rather than by the fuels.

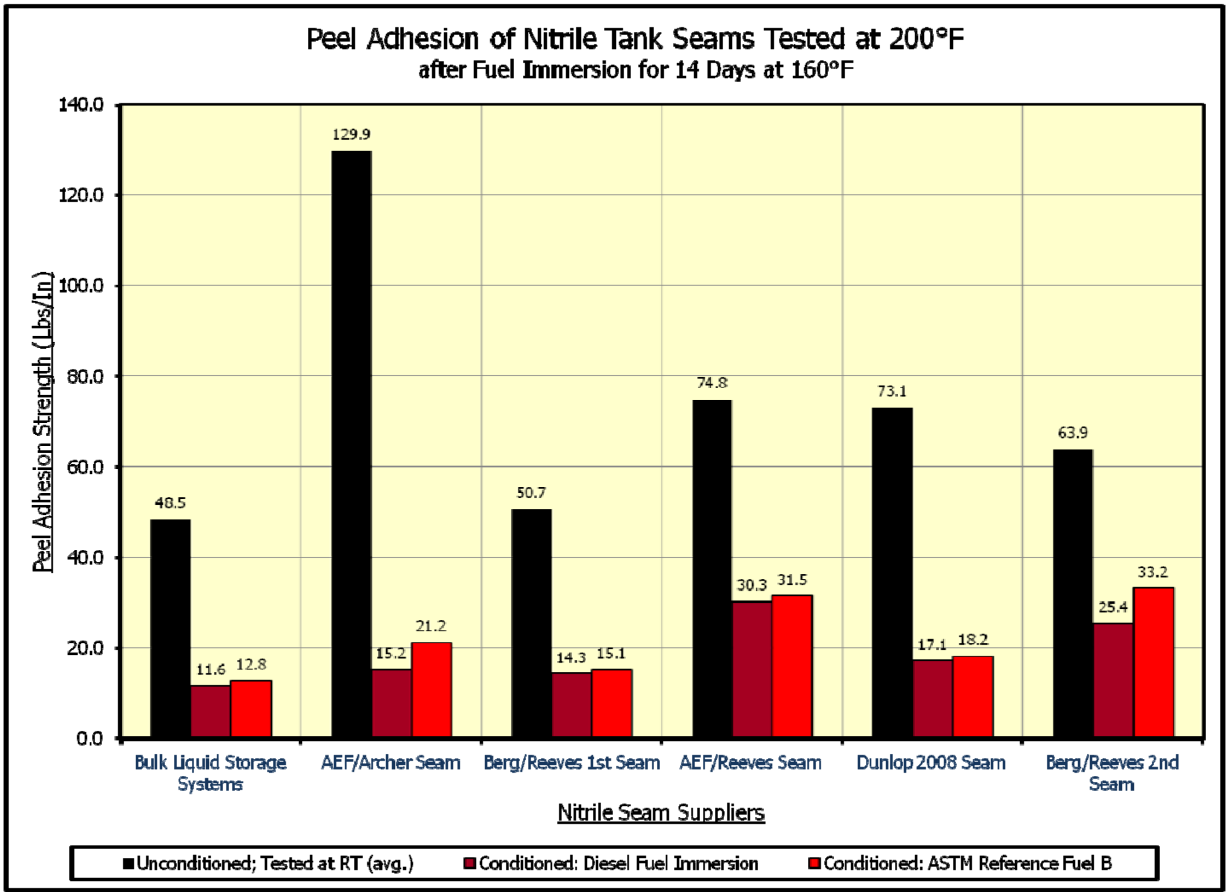

Figure 24. Comparison of peel adhesions for nitrile-coated fabric seams unconditioned and after conditioning in diesel fuel and ASTM fuel at 160 °F for 14 days. Specimens were tested at 200 °F.

In figure 25, the seam peel adhesion measured at room temperature of various suppliers after water immersion at 180 °F for time increments of 28, 42, and 70 days are compared. None of the seams were completely destroyed by immersion in water, but the AEF/Archer dropped from 130 to 40 lb/in, and the Dunlop dropped from 73 to 12.5 lb/in (below the MIL-T-52983G requirement of 15 lb/in). All other seams retained at least 65% of its peel adhesion value or above 26 lb/in when tested at room temperature. Figure 26 shows the effect of testing at elevated temperatures on the water peel adhesion strengths after water exposure. In this figure, the seam peel adhesion measured at 200 °F after water immersion at 180 °F for time increments of 28, 42, and 70 days are compared. The peel adhesion for all the seams, except for the Dunlop seam, remained relatively constant over the entire immersion period. All the seams maintained at least 15.5 lb/in peel adhesion, except the Dunlop material, which dropped to 3.7 lb/in when tested at 200 °F. The immersion water with the Dunlop specimens was observed to turn dark during the water immersion test, apparently due to the leaching out of water soluble additives or residual cure components. This was not observed in any of the other nitrile fabrics. The peel adhesion strengths actually increased with water exposure, demonstrating that water has no effect on seam adhesion.

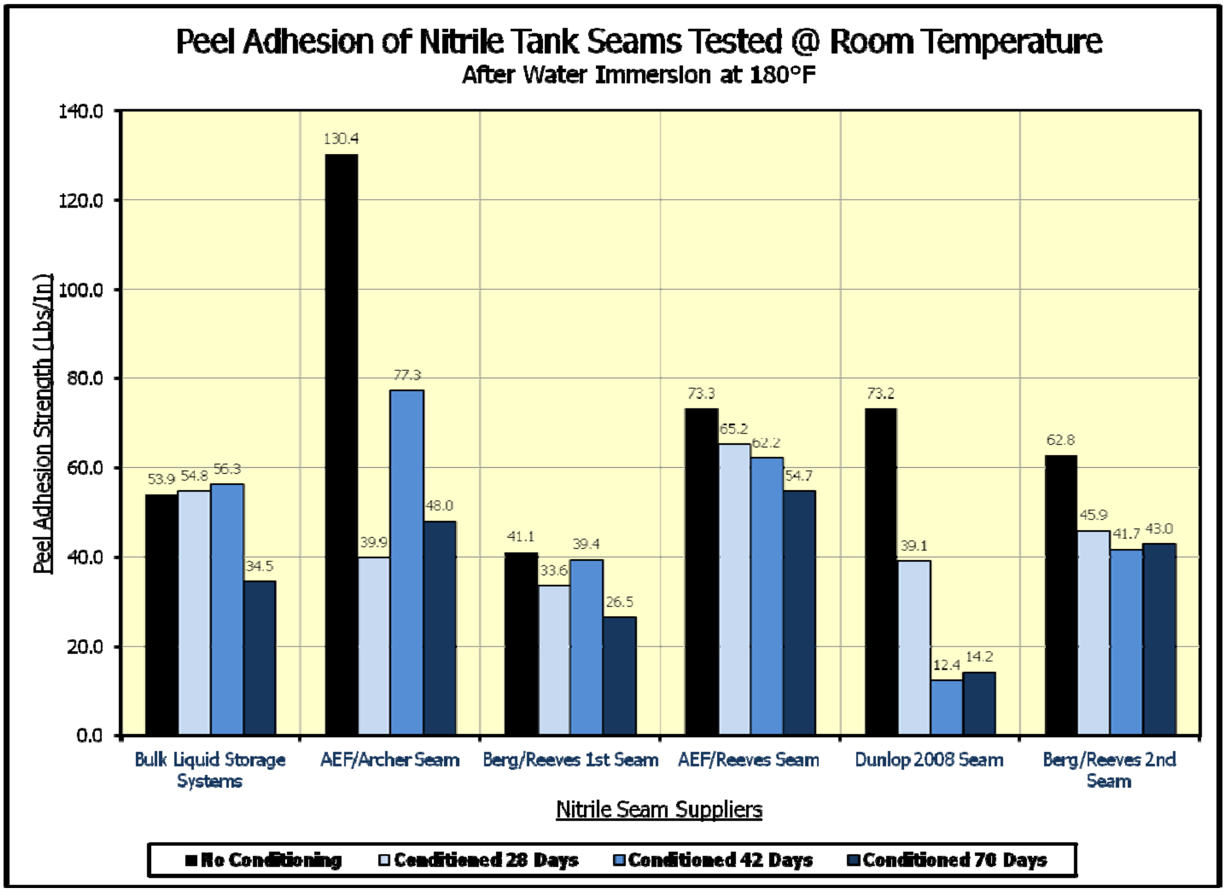

Figure 25. Peel adhesions results of nitrile-coated fabric seams after conditioning in water at 180 °F for 28, 42, and 70 days. Specimens were tested at room temperature.

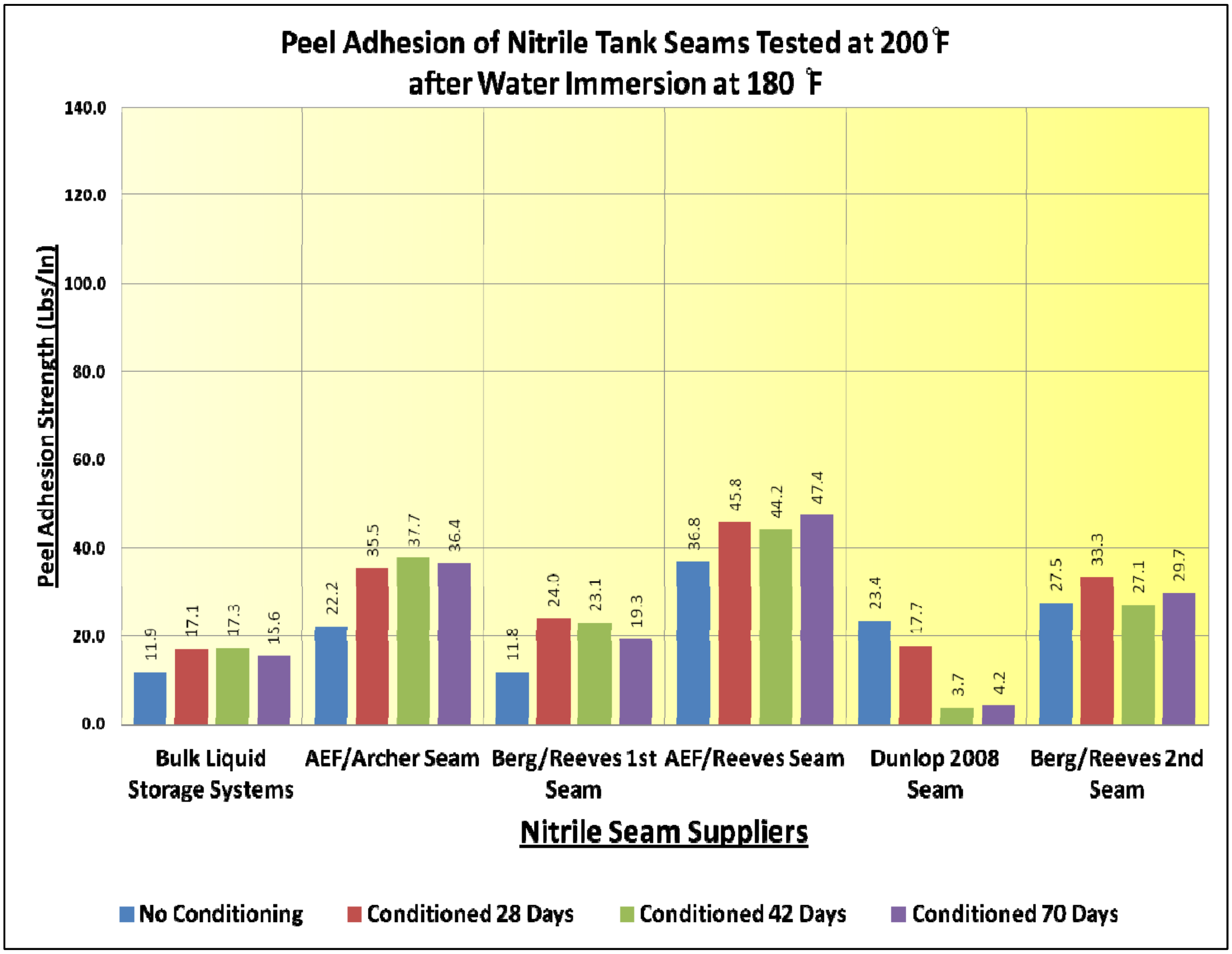

Figure 26. Peel adhesions results of nitrile-coated fabric seams after conditioning in water at 180 °F for 28, 42, and 70 days. Specimens were tested at 200 °F.

In figure 27, the seam peel adhesions measured at room temperature of various suppliers after extraction with JP-8 and then water immersion at 180 °F for time increments of 28, 42, and 70 days are compared. The peel adhesion for all the seams even for the Dunlop seam remained relatively constant over the entire immersion period. All of the adhesion values remained above 23.3 lb/in when tested at room temperature. In figure 28, the seam peel adhesions measured at 200 °F from various suppliers after extraction with JP-8 and then water immersion at 180 °F for time increments of 28, 42, and 70 days are compared. The peel adhesion values measured at 200 °F after water immersion of the fuel extracted seams seemed to be lower than that measured with the seams that were not extracted. The lowest values range from 8.1 lb/in for Dunlop to 22.5 lb/in for AEF/Reeves material.

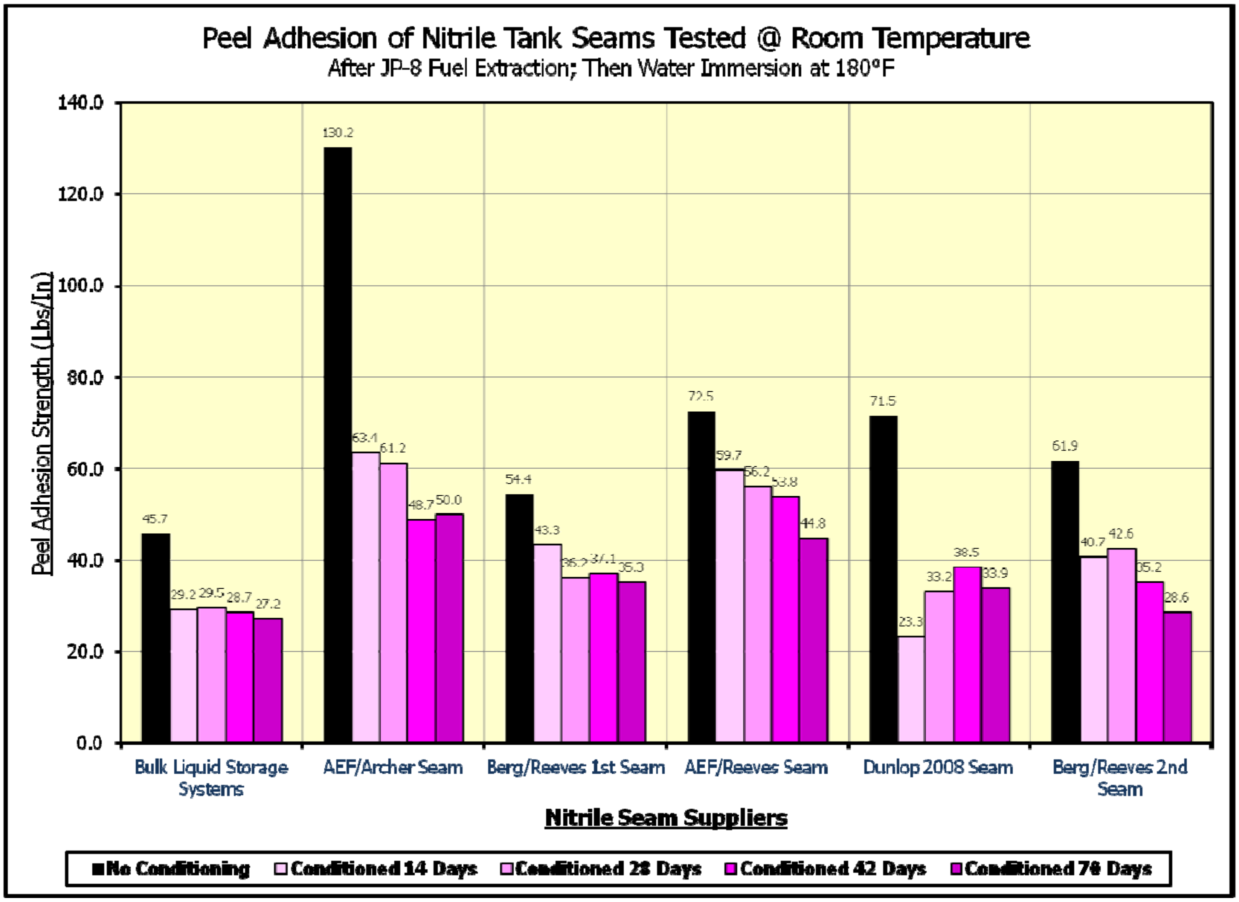

Figure 27. Peel adhesions results of nitrile-coated fabric seams after extraction in JP-8 and subsequent conditioning in water at 180 °F for 28, 42, and 70 days. Specimens were tested at room temperature.

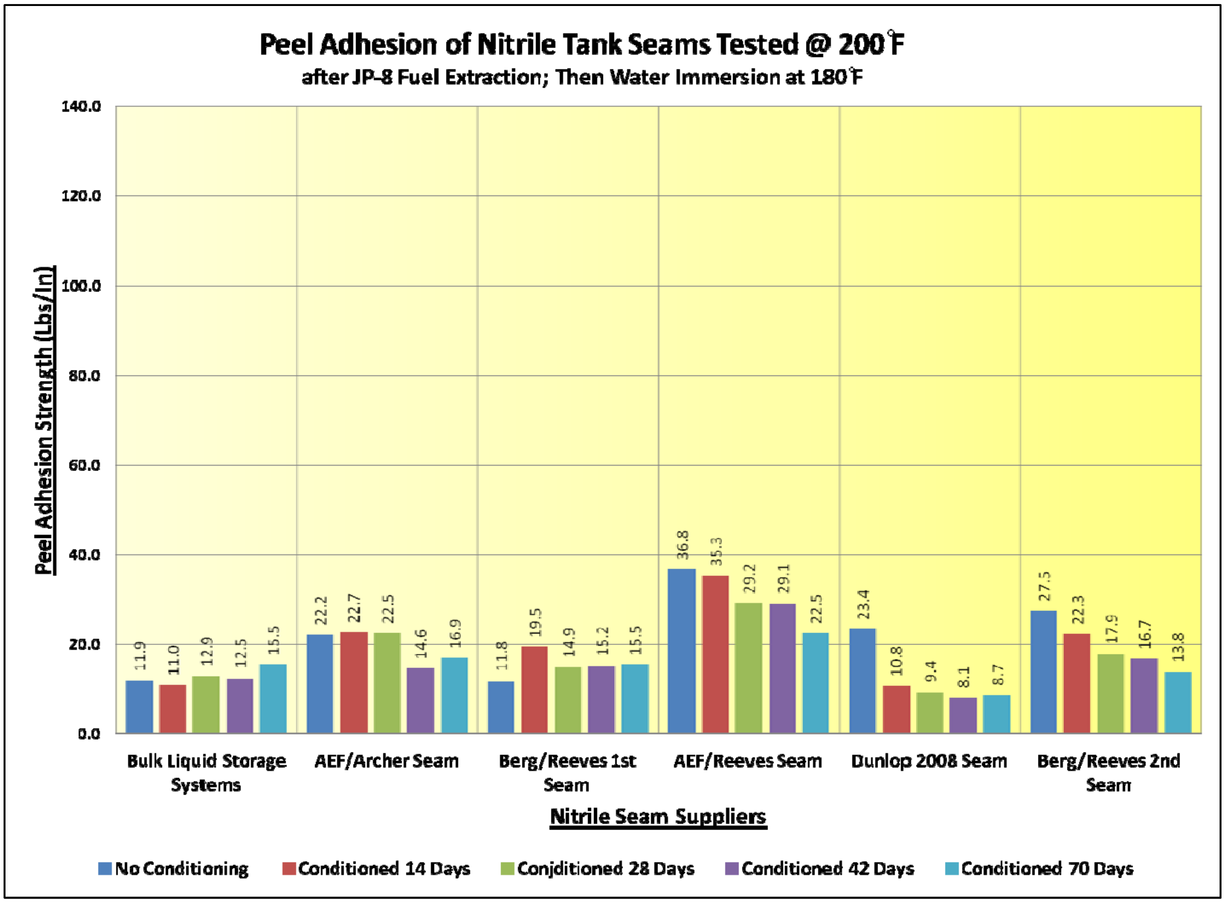

Figure 28. Peel adhesions results of nitrile-coated fabric seams after extraction in JP-8 and subsequent conditioning in water at 180 °F for 28, 42, and 70 days. Specimens were tested at 200 °F.

3.2.3 Dead Load Shear Resistance of Coated Fabric Seams

In table 6, only the BLSS seam material failed the dead load shear resistance test with the 100 lb/in stress at 200 °F. Because of safety concerns posed by the ARL safety office, we were not able to perform the dead load laboratory testing of the seams while immersed in fuel.

Table 6. Summary of nitrile-coated fabric seam physical properties.

Seam Tests	Seam Supplier	BLSS	AEF	Berg	AEF	Dunlop	Berg	Musthane
	Fabric Mfg.	BLSS	Archer	Reeves	Reeves	Dunlop	Reeves Production	Musthane
	Mfg. No.		Type 1	First Seam	Type 2	08 Material	235690-023	Musthane
1. Original Properties								
a. Breaking Strength at Room Temp., lb/in		559.8	656.2	520.5	700.7	712.6	702.0	413.7
b. Peel Adhesion at Room Temp., lb/in		41.4	112.4	46.5	71.9	71.4	67.0	47.8
2. Seam Conditioned 4 h at 200 °F Then Tested at 200 °F								
a. Breaking Strength, lb/in		446.7	551.7	390.0	532.0	615.0	460.0	374.0
b. Peel Adhesion, lb/in		11.9	21.7	11.8	36.8	23.4	27.5	11.1
3. After Immersion in Diesel Fuel for 14 Days at 160 °F								
Tested at Room Temp.								
a. Breaking Strength at Room Temp., lb/in		629.9	677.2	502.4	720.7	766.2	653.0	375.8
b. Peel Adhesion at Room Temp., lb/in		48.0	77.0	47.4	66.3	59.5	58.3	45.0
Seam Conditioned 4 h at 200 °F Then Tested at 200 °F								
a. Breaking Strength, lb/in		440.0	528.0	378.3	515.0	613.3	422.0	315.0
b. Peel Adhesion, lb/in		11.6	15.2	14.3	30.3	17.1	25.4	10.6
4. After Immersion in Ref. Fuel B for 14 Days at 160 °F								
Tested at Room Temp								
a. Breaking Strength at Room Temp., lb/in		627.6	732.0	508.3	672.5	736.4	676.7	420.2
b. Peel Adhesion at Room Temp., lb/in		26.4	42.5	32.7	53.7	37.6	49.9	15.0
Seam Conditioned 4 h at 200 °F Then Tested at 200 °F								
a. Breaking Strength, lb/in		423.3	530.0	373.3	526.7	590.0	389.0	294.0
b. Peel Adhesion, lb/in		12.8	21.2	15.1	31.5	18.2	33.2	7.7

Table 6. Summary of nitrile-coated fabric seam physical properties (continued).

Seam Tests	Seam Supplier	BLSS	AEF	Berg	AEF	Dunlop	Berg	Musthane
	Fabric Mfg.	**BLSS**	**Archer**	**Reeves**	**Reeves**	**Dunlop**	**Reeves Production**	**Musthane**
	Mfg. No.		**Type 1**	**First Seam**	**Type 2**	**08 Material**	**235690-023**	**Musthane**
5. After Water Immersion for 28 Days at 180 °F								
Tested at Room Temp.								
a. Breaking Strength, lb/in		516.1	564.9	433.8	595.7	613.1	522.2	372.0
b. Peel Adhesion, lb/in		54.8	39.9	33.6	65.2	39.1	45.9	N/T
Seam Conditioned 4 h at 200 °F Then Tested at 200 °F								
a. Breaking Strength, lb/in		420.0	493.3	345.0	475.0	450.0	440.0	N/T
b. Peel Adhesion, lb/in		17.1	35.5	24.0	45.8	17.7	33.3	N/T
6. After Water Immersion for 42 Days at 180 °F								
Tested at Room Temp.								
a. Breaking Strength, lb/in		488.6	552.0	414.7	587.4	561.6	544.1	375.6
b. Peel Adhesion, lb/in		56.3	77.3	39.4	62.2	12.4	41.7	N/T
Seam Conditioned 4 h at 200 °F Then Tested at 200 °F								
a. Breaking Strength, lb/in		400.0	488.3	350.0	500.0	435.0	503.0	N/T
b. Peel Adhesion, lb/in		17.3	37.7	23.1	44.2	3.7	27.1	N/T
7. After Water Immersion for 70 Days at 180 °F								
Tested at Room Temp.								
a. Breaking Strength, lb/in		482.8	526.8	415.2	577.9	607.2	518.5	N/T
b. Peel Adhesion, lb/in		34.5	48.0	26.5	54.7	14.2	43.0	3.7
Seam Conditioned 4 h at 200 °F Then Tested at 200 °F								
a. Breaking Strength, lb/in		380.0	496.7	356.7	491.7	472.0	470.0	N/T
b. Peel Adhesion, lb/in		15.6	36.4	19.3	47.4	4.2	29.7	2.0
Notes:								
N/T - Not Tested								

Table 6. Summary of nitrile-coated fabric seam physical properties (continued).

Seam Tests	Seam Supplier	BLSS	AEF	BERG	AEF	DUNLOP	BERG	MUSTHANE
	Fabric Mfg.	BLSS	Archer	Reeves	Reeves	Dunlop	Reeves Production	Musthane
	Mfg. No.		Type 1	First Seam	Type 2	08 Material	235690-023	MUSTHANE
1. After JP-8 Extraction, Water Immersion for 14 Days at 180 °F								
Tested at Room Temp.								
a. Breaking Strength, lb/in		526.4	527.0	N/T	592.0	588.1	N/T	N/T
b. Peel Adhesion, lb/in		29.2	63.4	43.3	59.7	23.3	40.7	N/T
Seam Conditioned 4 h at 200 °F Then Tested at 200 °F								
a. Breaking Strength, lb/in		380.0	497.0	N/T	490.0	513.0	N/T	N/T
b. Peel Adhesion, lb/in		11.0	22.7	19.5	35.3	10.8	22.3	N/T
2. After JP-8 Extraction, Water Immersion for 28 Days at 180 °F								
Tested at Room Temp.								
a. Breaking Strength, lb/in		533.6	555.7	N/T	591.5	558.5	N/T	N/T
b. Peel Adhesion, lb/in		29.5	61.2	36.2	56.2	33.2	42.6	N/T
Seam Conditioned 4 h at 200 °F Then Tested at 200 °F								
a. Breaking Strength, lb/in		403.0	456.0	N/T	490.0	510.0	N/T	N/T
b. Peel Adhesion, lb/in		12.9	22.5	14.9	29.2	9.4	17.9	N/T
3. After JP-8 Extraction, Water Immersion for 42 Days at 180 °F								
Tested @ Room Temp.								
a. Breaking Strength, lb/in		488.2	499.0	380.0	561.0	506.3	533.0	N/T
b. Peel Adhesion, lb/in		28.7	48.7	37.1	53.8	38.5	35.2	N/T

Table 6. Summary of nitrile-coated fabric seam physical properties (continued).

Seam Tests	Seam Supplier	BLSS	AEF	BERG	AEF	DUNLOP	BERG	MUSTHANE
	Fabric Mfg.	BLSS	Archer	Reeves	Reeves	Dunlop	Reeves Production	Musthane
	Mfg. No.		Type 1	First Seam	Type 2	08 Material	235690-023	MUSTHANE
Seam Conditioned 4 Hrs at 200 °F Then Tested at 200 °F								
a. Breaking Strength, lb/in		343.0	487.0	N/T	489.0	530.0	398.0	N/T
b. Peel Adhesion, lb/in		12.5	14.6	15.2	29.1	8.1	16.7	N/T
4. After JP-8 Extraction, Water Immersion for 70 Days at 180 °F								
Tested at Room Temp.								
a. Breaking Strength, lb/in		489.1	527.0	412.0	540.0	482	517.0	N/T
b. Peel Adhesion, lb/in		27.2	50.0	35.3	44.8	33.9	28.6	N/T
Seam Conditioned 4 h at 200 °F Then Tested at 200 °F								
a. Breaking Strength, lb/in		415.0	478.3	366.0	494	445	391.0	N/T
b. Peel Adhesion, lb/in		15.5	16.9	15.5	22.5	8.7	13.8	N/T
5. Dead Load Shear Resistance with 100 lb/in Stress at 200 °F								
No Slippage Or Seam Separation After 8 h, Pass or Fail		Fail	Pass	Pass	Pass	Pass	Pass	Pass
6. Type of Seam, Butt or Overlap		Overlap	Overlap	Butt	Overlap	Butt	Butt	Overlap
7. Seam Width, Inches		2	2.25	6.5	4	6	6.5	3
Notes:								
(A) Seam Failed								
(B) Specimens were too Weak to Test.								
N/T - Not Tested								

4. Conclusions

The use of a chamber with controlled temperature and humidity dramatically limited the variation in test results compared to tests being run under laboratory conditions. Only about half of the materials met the MIL-PRF-32233 requirement of 0.060 fl oz/ft^2/24 h. The Reeves nitrile-coated fabric material currently being used by Berg to supply the military with fuel tanks failed to meet the spec requirement. The one material containing PVF film barrier (BLSS) provided superior fuel diffusion results even at 160 °F. Our testing indicated that the PVF film delaminated during water immersion tests and would no longer serve as a fuel barrier and could possibly clog fuel drains and filters. Until these companies can demonstrate that fuel barrier films will remain bonded, they should not be used in this application. If fuel barrier film could be successfully adhered to the nitrile coating, wet spots currently observed in fielded collapsible fuel storage tanks might be reduced or totally eliminated during service.

Nitrile-coated fabric materials become stiff and brittle when creased at –25 °F after fuel extraction. Nitrile fuel tanks made from the materials evaluated in this program would not be able to be deployed after they had been in service than cleaned and stored. Most of the coated fabric materials experienced at least a six-fold increase in stiffness after accelerated weathering and fuel extraction.

The physical properties of the nitrile-coated fabric materials were not seriously affected by the accelerated weathering test. Weathering of these fabrics seemed to localize the degradation to the surface and not affect the interior section. This caused a small oxide layer to form and act as a barrier to further degradation. It might be useful in follow-on experiments to extend the time of exposure in the weatherometer. The slow deterioration of the exterior of the coating is likely not a problem; however it is the coating to nylon scrim adhesion that is the critical mechanical strength for composite integrity.

Conducting the breaking strength and peel adhesion at elevated temperature (200 °F) after conditioning in fuel and water appears to be an excellent indicator of seam integrity and should be used in specifications for future tank procurements. Seam dead load tests with 100 lb/in stress conducted in air at 200 °F and while immersed in fuel at 180 °F also need to be used in future tank procurements.

The Dunlop seams performed very poorly when immersed in water. The peel adhesion when tested at room temperature was only about 12 lb/in and was even lower (3.7 lb/in) when tested at 200 °F. The water used to condition the samples was very dark.

Visible wet spots/areas on the surface of tanks continue to pose a problem for the military to determine when the tanks are no longer safe to operate. These wet spots are probably a result of scratches in the coating, high fuel diffusion rates into the interior coating, manufacturing defects exposing woven textile, and microscopic pinholes in the rubber coating that allow fuel to enter the nylon woven fabric and wick to other areas of the tank surface. This problem was not addressed in this study but should be addressed in the future.

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List of Symbols, Abbreviations, and Acronyms

AEF	Avon Engineered Fabrications
ARL	U.S. Army Research Laboratory
ASTM	American Society for Testing and Materials
BLSS	Bulk Liquid Storage Systems
DMA	Dynamic Mechanical Analyzer
JP	jet propellant
PVF	Polyvinyl Fluoride
SWA	Southwest Asia

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