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Testing of Replacement Bag Material

by

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1.0 Introduction and Summary

Recently, the FB-Line bagout material was changed to simplify the processing of sand, slag, and crucible. The low density polyethylene (LDPE) and polyvinyl chloride (PVC) bags normally used to bag out cans of plutonium-bearing material have been replaced with nylon bags. Since LDPE and PVC are not soluble in the nitric acid dissolver solution used in F-Canyon, the flowsheet called for the existing cans of sand, slag, and crucible to be repackaged before they were added to the dissolver. Unlike LDPE and PVC, nylon is soluble in nitric acid. This allows cans to be packaged using normal practices and charged directly to the dissolver, thus saving handling requirements and personnel exposure [1].

The original nylon replacement material proved to be unsuitable for bagout operations due to a tendency to crack and leak during use [2]. The cracking was attributed to friction caused by a buildup of static electricity as the bags were pulled over the cans. To alleviate this problem and prevent leaks, two replacement materials, a thinner nylon with an antistatic agent added, color coded orange, and a high residual monomer plastic (HRMP), color coded pink, were selected for evaluation as bag materials. The orange bag material is currently being used for packaging; the pink material also has been judged to be acceptable if used with an anti-static agent.

FB-Line Operations has asked for measurement of the effects of radiation and heating on these materials. Specifically, they have requested a comparison of the material properties of the plastics before and after irradiation, a measurement of the amount of outgassing when the plastics are heated, and a calculation of the amount of radiolytic gas generation. Testing was performed on samples of approximately 2 mil thick nylon and 4 mil thick HRMP blown tubing. The samples were taken from material that is currently used or has been proposed for use in FB-Line. Many of the requested tests repeat tests previously performed on the original replacement and LDPE bag materials [3,4].

To evaluate the effect of irradiation on material properties, tensile stresses and elongations to break were compared for unirradiated and irradiated samples. Standard ASTM methods for the measurement of tensile plastic properties [5] and resistance to tear propagation [6] were used. Properties were measured both parallel to the direction of machining (MD) and transverse to the direction of machining (TD). Tensile strength measurements showed that the ultimate strengths of the replacement bag materials decreased by 15-16% in the MD orientation and 27-28% in the TD orientation after irradiation with 5×10^6 rad, a dose equivalent to about one year exposure in a plutonium can. Elongations to break also decreased for the HRMP material. Tear measurements gave a similar decrease in the ultimate strengths of the materials and little if any significant change in elongations to break. Although the 5×10^6 dose significantly degraded the properties of the replacement materials, their strengths remained superior to those previously measured for LDPE [4], even after irradiation.

Neither replacement material outgassed appreciably. When samples of both types of materials were heated in a sealed container to the maximum expected storage can temperature of 93°C, the pressure increased by about 3.0 psi. This pressure increase, most if not all of which can be attributed to heating of the air in the container, would not cause a can to fail. Using a representative G value of 1.6 molecules/100 ev, the amount of outgassing due to radiolysis was calculated to be negligible.

In conclusion, it may be stated that the results of the strength tests and the outgassing measurements and calculations demonstrate that the proposed replacement nylon bag materials (HRMP and orange anti-static material) are acceptable substitutes for LDPE and the original nylon with respect to mechanical properties.

2.0 Measurement of the Effect of Irradiation on Material Properties

To determine the effect of irradiation on bag strength, the nylon and high residual monomer bag materials were irradiated to 5 x 10^6 rad using a Cobalt-60 gamma source. As explained in the Appendix, these exposures are equivalent to the expected doses that the bag material would receive after sealing a plutonium can for about one year.

Irradiated and unirradiated samples were submitted to the SRTC Strategic Materials Technology Section for analyses of tensile properties. Standard ASTM tests were used to measure the tensile strength [5] and resistance to tearing [6]. Elongations to break were also measured for both tests. Test samples were cut from blown sheets of material identical to those used or proposed for use in FB-Line. Figure 1 depicts the samples.

Tests were performed using an Instron Model 1122 mechanical testing frame. Tensile test samples were stretched at a cross-head speed of 50 mm/min, and tear test samples were pulled apart at a speed of 200 mm/min.

Tables 1 and 2 report the results of the tensile and tear tests. Tensile test results include upper and lower yield loads, the ultimate load just prior to break, and elongation at break. Tear test results include lower yield and ultimate loads and the elongation at break. Results are statistically analyzed in Tables 3 and 4. These tables also list statistical analyses of results of previous tensile tests of the LDPE and original replacement bag materials [4]. The statistical analyses show that all replacement materials became weaker and that the HRMP and original nylon replacement materials became somewhat stiffer after irradiation. Tensile strengths of all replacement materials remained superior to those of unirradiated LDPE even after irradiation, however. The average ultimate loads for irradiated samples of the original replacement nylon, the HRMP, and the orange nylon with the anti-static agent were 15.9, 19.6, and 10.0 lbf in the machine direction and 13.2, 18.5, and 9.3 lbf in the transverse direction, compared to average ultimate loads of 8.2 lbf in the machine direction and 4.2 lbf in the transverse direction for unirradiated LDPE. (The tensile strength of the orange nylon material was lower than that of the original nylon material because of its reduced thickness, 2 mils versus 3-4 mil.)

The tear samples pulled apart at much lower loads than the tensile samples. The load measurements for the tear tests have large uncertainties because the instrument was operating at the lower end of its range, which is 0 to 10 lbf. Nevertheless, there were statistically significant decreases in tear resistances, ranging from 10% to 42%, after irradiation.

The increase in stiffness after irradiation is probably due to radiation-induced cross linking of the nylon fibers. The unirradiated samples exhibited oscillations in the load as they were stretched. This behavior was attributed to breaking and reformation of bonds between plastic fibers. These oscillations largely disappeared after irradiation, indicating that radiation-induced cross-linking may have acted to heal defects in the plastic. This effect would counteract stiffening and weakening of the plastics caused by irradiation.

3.0 Measurement of Outgassing due to Heating

A series of tests was conducted in which samples of the replacement bag materials were placed inside another closed vessel and heated to about 93°C inside a drying furnace [8]. Pressures were measured by a 0-30 psig dial pressure gauge. The entire assembly, including the pressure gauge, was heated inside the furnace. Three tests were conducted, one each with HRMP and the orange nylon samples, and one for calibration, with a small amount of water in the closed vessel. Theoretically, the calibration test should register an increase equal to the sum of the water vapor pressure and the increase due to volumetric expansion. The two tests with the plastic samples should give equilibrium pressure increases equal to the sum of the increase from volumetric expansion and the vapor pressure of condensable gases released by the plastic at the test temperature. Thus, for a sufficiently large sample, the pressure generated by heating the plastic should not depend on the amount of plastic in the container. Relatively large pieces of HRMP and nylon were used to ensure that the vapor space became saturated with offgasses from the plastic. HRMP and nylon samples weighing 0.79 and 1.49 grams, respectively, were heated in the 25-cm^3 test chamber. The weight-to-volume ratios for these tests, 0.032 and 0.060 grams/cm^3, exceeded the estimated weight-to-volume ratio for a bag inside the plutonium can, which is 12 grams/631 cm^3, or 0.019 grams/cm^3.

Figure 2 depicts transient pressure measurements for the outgassing tests. A comparison between measured and expected results for the water vapor calibration test demonstrates that these measurements are at least approximately correct. Theoretically, the equilibrium pressure for this test should be the sum of the increase due to heating of the air initially in the vessel and the vapor pressure of water. The pressure should increase 3.5 psi due to the temperature increase from room temperature, and 11.5 psi due to evaporation of water at the 93°C test temperature [9], for a total of 15.0 psi. The measured pressure rise for the calibration test was 15.5 psi. The plastic samples generated equilibrium pressure increases of about 2.9 psi, slightly less than what would be expected for air alone. This demonstrates that there is little if any outgassing from these plastics when they are heated to this temperature. The difference between the measured pressure increases and the increase predicted for heating of air probably can be attributed to pressure gauge errors.

4.0 Calculation of Outgassing due to Irradiation

The amount of outgassing from the nylon bag material due to irradiation has been calculated based on the irradiation level and an estimated G-value for gas generation. A calculation was performed in lieu of a measurement because the volume of gas that would be generated is too small to measure with existing site equipment. In a separate study, measurements under vacuum gave G-values ranging up to 1.6 molecules/100 ev for various types of nylon [10]; this highest cited value is used in the calculations for both HRMP and nylon. Two-thirds of the gas that was generated was hydrogen, and most of the remainder was carbon monoxide.

With an assumed G-value of 1.6 molecules/100 ev, a plutonium can bag is calculated to generate only about 2.5 cm^3 of vapor in a service time of 1 year, based on a decay rate of 1×10^9 disintegrations/min/100 cm^2, or a total exposure of 5×10^6 rad. This volume is insignificant compared to the air space enclosing the bags between the inner and outer plutonium cans, so there should not be a significant pressure increase due to radiolytic outgassing. The volume between the two cans has been measured to be 631 cm^3; the calculated radiolytic gas generation is only 0.4% of this total. The Appendix presents details of the calculation of the amount of gas generation.

5.0 Conclusions and Recommendations

To evaluate the effect of irradiation on material properties, tensile stresses and elongations to break were compared for unirradiated and irradiated samples, using standard ASTM methods for the measurement of tensile plastic properties and resistance to tear propagation. Properties were measured both parallel to the direction of machining (MD) and transverse to the direction of machining (TD). Tensile strength measurements showed that the ultimate strengths of the replacement bag materials decreased by 15-16% in the MD orientation and 27-28% in the TD orientation after irradiation with 5×10^6 rad, a dose equivalent to about one year exposure in a plutonium can. Elongations to break also decreased for the HRMP material. Tear measurements gave a similar decrease in the ultimate strengths of the materials and little if any significant change in elongations to break. Although the 5×10^6 dose significantly degraded the properties of the replacement materials, their strengths remained superior to those previously measured for LDPE, even after irradiation.

Neither replacement material outgassed appreciably. When samples of both types of materials were heated in a sealed container to the maximum expected storage can temperature of 93°C, the pressure increased by about 2.9 psi. This pressure increase, most if not all of which can be attributed to heating of the air in the container, would not cause a can to fail. Using a representative G value of 1.6 molecules/100 ev, the amount of outgassing due to radiolysis was calculated to be negligible.

In conclusion, it may be stated that the results of the strength tests and the outgassing measurements and calculations demonstrate that the proposed replacement bag materials (HRMP and orange anti-static material) are an acceptable substitute for LDPE with respect to mechanical properties.

6.0 References

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Table 1. Tensile Stress and Elongation Measurements for Plastic Materials

Material	Orientation	Dose (Rad)	Gauge Length (in)	Width (in)	Thickness (in)	Upper Yield Load (lbf)	Lower Yield Load (lbf)	Ultimate Tensile Load (lbf)	Elongation at Break (mm)	Elongation at Break (%)	Failure Location
HRMP	TD	None	5.313	0.7081	0.0038	16.6	14.9	24.0	383.6	284	reduced section
HRMP	TD	None	5.039	0.7354	0.0036	18.0	16.4	20.2	193.0	151	shoulder
HRMP	TD	None	5.141	0.7448	0.0038	18.6	16.8	27.0	433.0	332	reduced section
HRMP	TD	None	5.184	0.7442	0.0040	18.1	15.5	27.5	460.3	350	reduced section
HRMP	TD	None	5.234	0.7512	0.0042	18.2	16	27.5	467.8	352	reduced section
HRMP	MD	None	5.397	0.7298	0.0038	18.8	18.1	21.0	251.0	183	shoulder
HRMP	MD	None	5.345	0.7396	0.0040	19.0	18.4	23.0	292.1	215	shoulder
HRMP	MD	None	5.283	0.7497	0.0040	18.5	18	24.0	331.0	247	shoulder
HRMP	MD	None	5.294	0.73	0.0040	18.7	18.2	22.0	272.5	203	reduced section
HRMP	MD	None	5.212	0.7293	0.0040	17.4	16.9	25.5	431.2	326	reduced section
HRMP	TD	5x10^6	5.091	0.7406	0.0042	16.4	14.8	21.0	326.4	252	shoulder
HRMP	TD	5x10^6	5.292	0.735	0.0040	15.4	14	18.2	277.1	206	reduced section
HRMP	TD	5x10^6	5.324	0.738	0.0040	15.5	14.2	18.0	220.0	163	shoulder
HRMP	TD	5x10^6	5.294	0.7762	0.0040	13.7	13.1	19.2	318.4	237	reduced section
HRMP	TD	5x10^6	5.277	0.7348	0.0040	12.9	12.6	16.2	255.1	190	shoulder
HRMP	MD	5x10^6	5.406	0.7502	0.0040	16.6					reject
HRMP	MD	5x10^6	5.295	0.7308	0.0040	15.8	15.2	18.4	270.7	201	reduced section
HRMP	MD	5x10^6	5.188	0.743	0.0040	19.0	18.7	22.0	242.0	184	reduced section
HRMP	MD	5x10^6	5.156	0.7196	0.0040	15.2	15.2	19.8	270.3	206	reduced section
HRMP	MD	5x10^6	5.053	0.7476	0.0040	14.6	14.6	18.0	229.0	178	shoulder
Nylon	TD	None	5.229	0.7132	0.0020	11.6	9.8	12.5	177.3	133	reduced section
Nylon	TD	None	5.334	0.72	0.0020	13.4	10.6	13.2	101.0	75	shoulder
Nylon	TD	None	5.223	0.7074	0.0020	13.0	10.4	13.4	105.3	79	reduced section
Nylon	TD	None	5.201	0.7104	0.0020	12.3	9.8	12.3			reject
Nylon	TD	None	5.327	0.728	0.0020	12.8					reject
Nylon	MD	None	5.189	0.7088	0.0020	11.5	11.4	11.5	121.1	92	shoulder
Nylon	MD	None	5.307	0.7066	0.0020	11.4	11.2	11.6	151.9	113	reduced section
Nylon	MD	None	5.327	0.703	0.0020	11.2	11.1	12.0	181.0	134	reduced section
Nylon	MD	None	5.376	0.7156	0.0020	11.4	11.2	11.8	142.7	105	shoulder
Nylon	MD	None	5.258	0.7092	0.0020	12.0	11.9	13.2	196.6	147	reduced section

Table 1. Tensile Stress and Elongation Measurements for Plastic Materials (continued)

Material	Orientation	Dose (Rad)	Gauge Length (in)	Width (in)	Thickness (in)	Upper Yield Load (lbf)	Lower Yield Load (lbf)	Ultimate Tensile Load (lbf)	Elongation at Break (mm)	Elongation at Break (%)	Failure Location
Nylon	TD	5x10^6	5.222	0.6778	0.0020	11.1	8.6	11.2	73.6	55	reduced section
Nylon	TD	5x10^6	5.084	0.72	0.0020	11.1	9.6	11.1	38.3	30	shoulder
Nylon	TD	5x10^6	5.285	0.7002	0.0020	8.4	8.0	8.4	99.0	74	shoulder
Nylon	TD	5x10^6	5.395	0.6623	0.0020	7.3	6.8	7.6	183.0	134	reduced section
Nylon	TD	5x10^6	5.371	0.731	0.0020	8.0	7.5	8.2	194.7	143	shoulder
Nylon	MD	5x10^6	5.346	0.7486	0.0020	10.1	9.9	11.1	228.0	168	shoulder
Nylon	MD	5x10^6	5.119	0.71	0.0020	10.6	10.6	10.8	116.0	89	shoulder
Nylon	MD	5x10^6	5.384	0.7272	0.0020	7.8	8.3	8.3	132.3	97	reduced section
Nylon	MD	5x10^6	5.224	0.7182	0.0020	7.4	7.4	10.0	262.9	198	reduced section
Nylon	MD	5x10^6	5.266	0.715	0.0020	7.4	7.4	10.0	262.3	196	shoulder

Table 2. Tear Stress and Elongation Measurements for Plastic Materials

Material	Orientation	Dose	Gauge Length (in)	Width (in)	Thickness (in)	Initial Tear Load (lbf)	Ultimate Load (lbf)	Elongation (mm)	Elongation (%)
HRMP	TD	None	2.03	1.02	0.0040	0.36	0.55	60.2	117
HRMP	TD	None	2.06	1.03	0.0040	0.30	0.50	56.6	108
HRMP	TD	None	2.02	1.03	0.0040	0.30	0.55	56.3	110
HRMP	TD	None	2.07	1.01	0.0038	0.35	0.55	55.8	106
HRMP	TD	None	1.99	1.03	0.0034	0.35	0.60	59.0	117
HRMP	MD	None	2.08	0.99	0.0038	0.30	0.40	Rejected	
HRMP	MD	None	1.97	1.03	0.0040	0.30	0.40	54.6	109
HRMP	MD	None	2.06	1.02	0.0040	0.30	Rejected		
HRMP	MD	None	2.04	1.02	0.0040	0.35	0.40	53.9	104
HRMP	MD	None	2.12	1.06	0.0040	0.35	0.45	51.9	97
HRMP	TD	5x10^6	1.99	1.05	0.0040	0.30	0.40	57.9	115
HRMP	TD	5x10^6	2.03	1.03	0.0040	0.25	0.40	53.0	103
HRMP	TD	5x10^6	2.06	1.03	0.0040	0.30	0.40	57.3	110
HRMP	TD	5x10^6	2.02	1.00	0.0040	0.35	0.45	59.7	116
HRMP	TD	5x10^6	2.08	1.03	0.0040		0.40	58.2	110

Table 2. Tear Stress and Elongation Measurements for Plastic Materials (continued)

Material	Orientation	Dose	Gauge Length (in)	Width (in)	Thickness (in)	Initial Tear Load (lbf)	Ultimate Load (lbf)	Elongation (mm)	Elongation (%)
HRMP	MD	5x10^6	2.03	1.02	0.0040	0.30	0.38	56.1	109
HRMP	MD	5x10^6	2.06	1.02	0.0040	0.25	0.35	62.2	119
HRMP	MD	5x10^6	2.02	1.04	0.0040	0.20	0.35	62.1	121
HRMP	MD	5x10^6	2.02	1.03	0.0040	0.30	0.35	61.9	120
HRMP	MD	5x10^6	2.03	1.04	0.0040	0.20	0.35	53.0	103
Nylon	TD	None	2.00	1.02	0.0020	0.15	0.30	55.3	109
Nylon	TD	None	2.04	1.01	0.0020	0.20	0.30	51.0	98
Nylon	TD	None	2.02	1.02	0.0020	0.23	0.26	55.9	109
Nylon	TD	None	2.01	1.02	0.0020	0.20	0.30	53.9	106
Nylon	TD	None	1.93	1.04	0.0020	0.25	0.35	57.6	117
Nylon	MD	None	2.01	1.02	0.0020	0.13	0.15	53.6	105
Nylon	MD	None	2.02	1.03	0.0020	0.15	0.20	55.7	108
Nylon	MD	None	2.11	1.03	0.0020	0.15	0.20	55.5	104
Nylon	MD	None	2.08	1.04	0.0020	0.15	0.20	49.4	94
Nylon	MD	None	2.03	1.04	0.0020	0.15	0.20	48.3	94
Nylon	TD	5x10^6	2.01	1.03	0.0020	0.10	0.30	57.4	112
Nylon	TD	5x10^6	2.01	1.02	0.0020	0.10	0.30	58.0	114
Nylon	TD	5x10^6	2.06	1.00	0.0020	0.15	0.30	52.6	101
Nylon	TD	5x10^6	2.01	1.01	0.0020	0.15	0.30	55.0	108
Nylon	TD	5x10^6	2.05	0.97	0.0020	0.10	0.25	55.7	107
Nylon	MD	5x10^6	2.06	1.03	0.0020	0.13	0.15	54.2	104
Nylon	MD	5x10^6	2.07	1.03	0.0020	0.13	0.15	55.8	106
Nylon	MD	5x10^6	2.03	1.02	0.0020	0.13	0.15	54.7	106
Nylon	MD	5x10^6	2.04	1.02	0.0020	0.10	0.15	54.7	106
Nylon	MD	5x10^6	2.07	1.02	0.0020	0.13	0.15	53.7	102

Table 3. Effect of 5x10⁶ Rad Irradiation on Material Properties

Material/ Orientation	Test Type	Dose (rad)	Upper Yield Load (lbf)	Lower Yield Load (lbf)	Ultimate Load (lbf)	Elongation to Break (%)
HRMP/MD	Tensile	None	18.5±0.6	17.9±0.6	23.1±1.7	235±56
HRMP/MD	Tensile	$5x10^6$	16.2±1.7	15.9±1.9	19.6±1.8	192±13
HRMP/TD	Tensile	None	17.9±0.8	15.9±0.7	25.2±3.2	294±84
HRMP/TD	Tensile	$5x10^6$	14.8±1.4	13.7±0.9	18.5±1.8	210±36
Nylon/MD	Tensile	None	11.5±0.3	11.4±0.3	12.0±0.7	118±22
Nylon/MD	Tensile	$5x10^6$	8.7±1.6	8.7±1.5	10.0±1.1	150±53
Nylon/TD	Tensile	None	12.6±0.7	10.2±0.4	12.9±0.5	96±33
Nylon/TD	Tensile	$5x10^6$	9.2±1.8	8.1±1.1	9.3±1.7	87±49
HRMP/MD	Tear	None	-----	0.33±0.03	0.42±0.03	103±6
HRMP/MD	Tear	$5x10^6$	-----	0.25±0.05	0.36±0.01	114±8
HRMP/TD	Tear	None	-----	0.33±0.03	0.55±0.04	112±5
HRMP/TD	Tear	$5x10^6$	-----	0.30±0.04	0.41±0.02	111±5
Nylon/MD	Tear	None	-----	0.15±0.01	0.19±0.02	101±7
Nylon/MD	Tear	$5x10^6$	-----	0.12±0.01	0.15±0.00	105±2
Nylon/TD	Tear	None	-----	0.21±0.04	0.30±0.03	108±7
Nylon/TD	Tear	$5x10^6$	-----	0.12±0.03	0.29±0.02	108±5
Previous Results [4]						
LDPE/MD	Tensile	None	-----	4.1±0.40	8.2±1.0	225±60
LDPE/TD	Tensile	None	-----	3.4±0.37	4.2±0.2	477±10
Nylon/TD	Tensile	None	-----	12.5±0.65	18.0±1.4	292±51
Nylon/TD	Tensile	$5x10^6$	-----	13.1±0.11	13.2±0.2	97±35
Nylon/MD	Tensile	None	-----	12.6±0.56	18.7±1.5	308±35
Nylon/MD	Tensile	$5x10^6$	-----	13.0±0.79	15.9±2.1	213±50

Note: Plus/minus indicates one standard deviation for sample of five measurements.

Table 4. Significance of the Effect of Irradiation on Material Properties

Material/ Orientation	Test Type	Effect			
		Upper Yield Load	Lower Yield Load	Ultimate Load	Elongation to Break
HRMP/MD	Tensile	-12%	-11%	-15%	-18%
HRMP/TD	Tensile	-17%	-14%	-27%	-29%
Nylon/MD	Tensile	-25%	-23%	-16%	NSE
Nylon/TD	Tensile	-27%	-20%	-28%	NSE
HRMP/MD	Tear	-----	-25%	-15%	+11%
HRMP/TD	Tear	-----	-10%	-25%	NSE
Nylon/MD	Tear	-----	-15%	-21%	NSE
Nylon/TD	Tear	-----	-42%	NSE	NSE
Previous Results [4]					
Nylon/MD	Tensile	-----	NSE	-15%	-31%
Nylon/TD	Tensile	-----	+5%	-27%	-67%

Note: Plus/minus indicates change from measured property of unirradiated sample. "NSE" means that the effect of irradiation is not significant at the 90% one-sided confidence level according to the Student's t test [7].

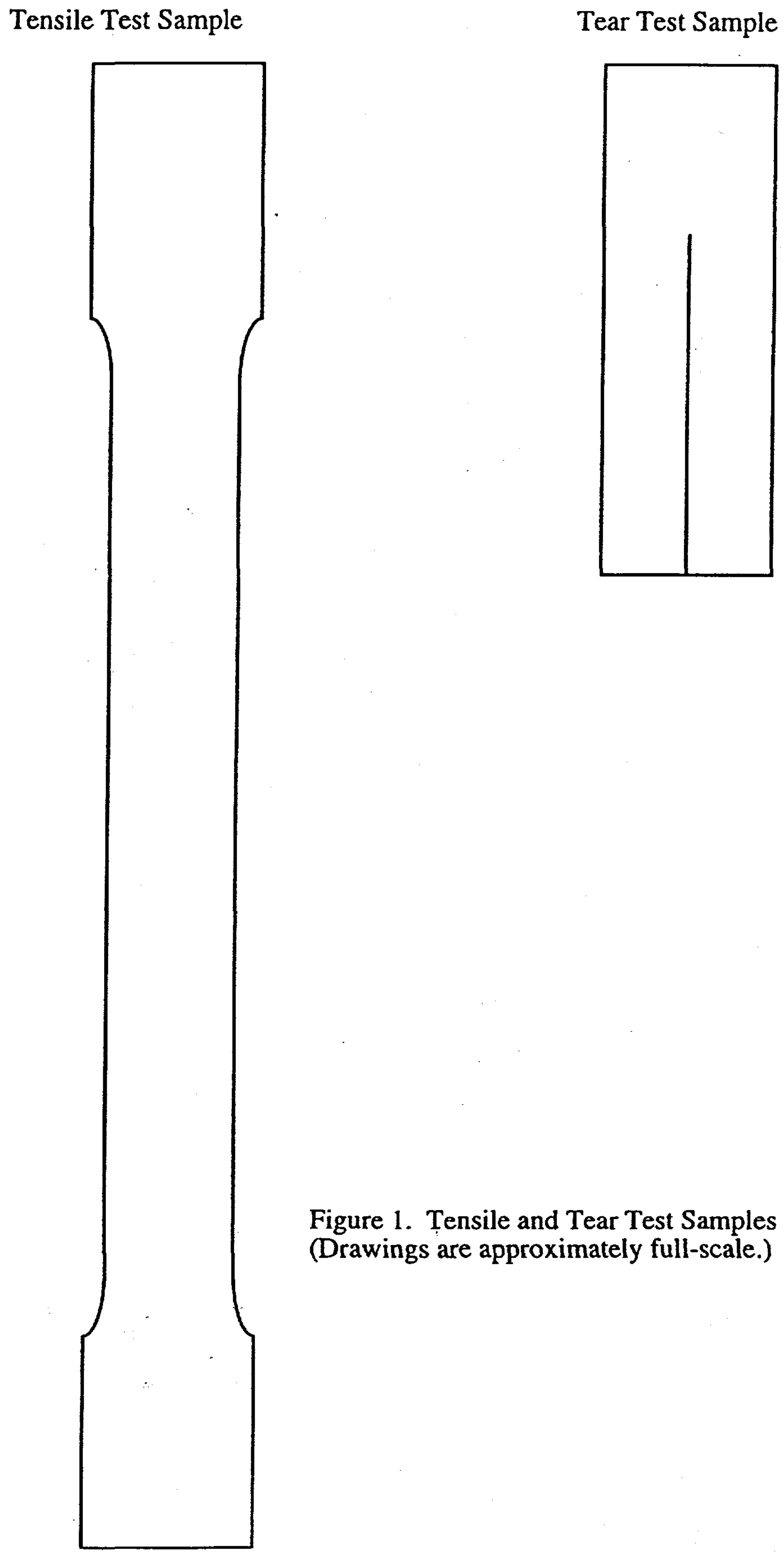

Figure 1. Tensile and Tear Test Samples
(Drawings are approximately full-scale.)