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TEAR, TENSILE, AND PUNCTURE TESTING OF LLUMAR POLYESTER SAFETY FILMS

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INTRODUCTION

This report presents the results of tear, tensile, and puncture testing conducted on samples of Polyester Safety Film material. The testing was authorized by Lisa Joyce of Eastman Performance Films, LLC on March 7, 2018. The initial testing and data analysis were completed March 26, 2018 with yield data being analyzed April 3, 2018. The scope of work was limited to conducting tear, tensile, and puncture tests on the submitted samples and reporting the results.

CONCLUSIONS

Tear Testing Conclusions

Sample	Average Tear Resistance Force, lbf	Average Resistance to Tearing, lbf/in
4 mil Machine Direction	14.2	3454
4 mil Transverse Direction	13.8	3375
7 mil Machine Direction	26.3	3656
7 mil Transverse Direction	26.1	3622
8 mil Machine Direction	27.8	3396
8 mil Transverse Direction	28.6	3483
13 mil Machine Direction	45.9	3328
13 mil Transverse Direction	48.0	3475

*See note in Test Results regarding ASTM D1004-13

Tensile Testing Conclusions

Sample	Average Break Strength Force, lbf	Average Tensile Strength at Break, psi	Average Elongation at Break, %
4 mil Machine Direction	93	22732	138
4 mil Transverse Direction	102	24915	106
7 mil Machine Direction	149	20450	149
7 mil Transverse Direction	178	24160	129
8 mil Machine Direction	184	22174	164
8 mil Transverse Direction	255	31174	98
13 mil Machine Direction	268	19180	171
13 mil Transverse Direction	297	21643	163

CONCLUSIONS Continued

Tensile Testing Conclusions Continued

Sample	Average Yield Strength Force, lbf	Average Yield Strength, psi	Average Elongation at Yield, %
4 mil Machine Direction	71	17222	8
4 mil Transverse Direction	65	15910	5
7 mil Machine Direction	124	16958	8
7 mil Transverse Direction	119	16159	6
8 mil Machine Direction	141	17004	8
8 mil Transverse Direction	128	15621	4
13 mil Machine Direction	226	16275	13
13 mil Transverse Direction	217	15772	8

Puncture Testing Conclusions

Sample	Average Puncture Strength, lbf
4 mil	65.1
7 mil	118.0
8 mil	153.3
13 mil	212.3

SAMPLE IDENTIFICATION

Four types of material were received for testing. The material consisted of rolls of polyester safety film in thicknesses of 4, 7, 8, and 13 mil, identified as LLumar SCL SR PS4, SCL SR PS7, SCL SR PS8 and SCL SR PS13, respectively. Specimens were sectioned using dies (tear), film cutters (tensile), and scissors (puncture). Material thickness was measured with adhesive removed and is shown below.

Sample	Thickness [in]
4 mil	0.0041
7 mil	0.0072
8 mil	0.0082
13 mil	0.0138

TEST METHOD

The specimens were allowed to condition at standard laboratory conditions of $72 \pm 4^{\circ}\text{F}$ and $50 \pm 5\%$ relative humidity for at least 40 hours prior to testing. The thickness of each material was determined for resistance and strength calculations. For this, representative samples were taken from each material thickness, the adhesive was removed with an organic solvent, the samples were cleaned with isopropyl alcohol and an average thickness was determined. All testing was conducted with the adhesive layer intact on the specimens. Testing was performed according to the standards detailed below, with notes of parameters and/or deviations.

Test Method	Test Method Title	Parameters and/or Deviations from Method
ASTM D1004-13	Standard Test Method for Tear Resistance (Graves Tear) of Plastic Film and Sheeting	Die Cut Specimens Test Speed: 2 in/min.
ASTM D882-12	Standard Test Method for Tensile Properties of Thin Plastic Sheeting	2" Grip Separation 1" x 10" Specimens, nominal Test Speed: 20 in/min Initial Strain Rate: 10.0 in/in·min
ASTM D4830/D4830M-98(2014) ^{e1}	Standard Test Method for Characterizing Thermoplastic Fabrics Used in Roofing and Waterproofing – Section 7	3" x 3" Specimens Test Speed: 12 in/min

CALIBRATED TEST EQUIPMENT

Honeywell Temp/RH Chart Recorder, S/N 7852 243000007, ID MM190-024
 MTS Universal Test Machine, Mdl Qtest / 50LP, System #1532, ID MM210-009.3 & 6
 MTS Load Cell, 2250lbf Capacity, S/N 205974, ID MM210-009.1
 Interface Load Cell, 225lbf Capacity, S/N 677238, ID PT-163-042
 Interface Load Cell, 22.5lbf Capacity, S/N 667350, ID PT-163-039
 Mitutoyo Digital 8" Calipers, S/N 0006565, ID MM160-068
 Mitutoyo Micrometer, S/N 47007254, ID PT-163-048
 Mitutoyo Dial 12" Calipers, ID MM160-008

TEST RESULTS

Tear Results

Sample	Specimen	Thickness, in	Tear Resistance Force, lbf	Resistance to Tearing, lbf/in *
4 mil Machine Direction	1	0.0041	15.7	3834
	2	0.0041	13.1	3199
	3	0.0041	13.9	3398
	4	0.0041	13.7	3338
	5	0.0041	14.4	3501
Average			14.2	3454
Standard Deviation			1.0	239
4 mil Transverse Direction	1	0.0041	13.0	3172
	2	0.0041	13.7	3332
	3	0.0041	13.9	3382
	4	0.0041	13.0	3176
	5	0.0041	15.6	3813
Average			13.8	3375
Standard Deviation			1.1	262
7 mil Machine Direction	1	0.0072	29.5	4099
	2	0.0072	24.6	3410
	3	0.0072	26.7	3707
	4	0.0072	25.7	3564
	5	0.0072	25.2	3500
Average			26.3	3656
Standard Deviation			1.9	270
7 mil Transverse Direction	1	0.0072	26.7	3711
	2	0.0072	24.6	3413
	3	0.0072	25.8	3583
	4	0.0072	26.8	3716
	5	0.0072	26.6	3688
Average			26.1	3622
Standard Deviation			0.9	129

TEST RESULTS Continued

Tear Results Continued

Sample	Specimen	Thickness, in	Tear Resistance Force, lbf	Resistance to Tearing, lbf/in *
8 mil Machine Direction	1	0.0082	28.3	3450
	2	0.0082	27.9	3401
	3	0.0082	26.7	3259
	4	0.0082	28.5	3475
	5	0.0082	27.8	3393
Average			27.8	3396
Standard Deviation			0.7	84
8 mil Transverse Direction	1	0.0082	26.0	3167
	2	0.0082	29.0	3541
	3	0.0082	30.4	3711
	4	0.0082	29.3	3568
	5	0.0082	28.1	3428
Average			28.6	3483
Standard Deviation			1.7	203
13 mil Machine Direction	1	0.0138	48.5	3513
	2	0.0138	44.4	3218
	3	0.0138	46.1	3341
	4	0.0138	43.4	3143
	5	0.0138	47.3	3425
Average			45.9	3328
Standard Deviation			2.1	150
13 mil Transverse Direction	1	0.0138	46.3	3355
	2	0.0138	48.7	3527
	3	0.0138	48.6	3525
	4	0.0138	47.9	3468
	5	0.0138	48.3	3500
Average			48.0	3475
Standard Deviation			1.0	71

*ASTM D1004-13 subsection 1.1.1 states, "Although resistance to tear can be expressed in newtons per microns, (pounds-force per mil) of specimen thickness, this is only advisable where correlation for the particular material being tested has been established. In most cases, comparison between films of dissimilar thickness is not valid."

Nominal thickness of sample material was used for Resistance to Tearing calculations. Measured thicknesses of individual specimens with adhesive is available upon request.

TEST RESULTS Continued

Tensile Results

Sample	Specimen	Width, in	Thickness, in	Break Strength Force, lbf	Tensile Strength at Break, psi	Ultimate Elongation, %
4 mil. Machine Direction	7	1.008	0.0041	91	22008	126
	8	1.004	0.0041	93	22552	137
	9	0.996	0.0041	100	24557	168
	10	0.994	0.0041	85	20906	108
	11	0.998	0.0041	97	23636	151
Average				93	22732	138
Standard Deviation				6	1418	23
4 mil. Transverse Direction	7	1.006	0.0041	102	24765	100
	8	1.008	0.0041	108	26183	125
	10	1.000	0.0041	100	24316	96
	11	0.996	0.0041	104	25521	121
	12	0.988	0.0041	96	23789	86
Average				102	24915	106
Standard Deviation				4	952	17
7 mil. Machine Direction	6	1.004	0.0072	152	20994	153
	8	1.001	0.0072	152	21109	163
	9	1.036	0.0072	152	20387	153
	10	1.005	0.0072	146	20234	150
	11	1.023	0.0072	144	19525	128
Average				149	20450	149
Standard Deviation				4	640	13
7 mil. Transverse Direction	1	1.028	0.0072	182	24555	125
	3	1.010	0.0072	175	24053	136
	4	0.998	0.0072	170	23681	139
	5	1.042	0.0072	178	23745	131
	6	1.028	0.0072	183	24765	117
Average				178	24160	129
Standard Deviation				5	484	9

TEST RESULTS Continued

Tensile Results Continued

Sample	Specimen	Width, in	Thickness, in	Yield Strength Force, lbf	Yield Strength, psi	Elongation at Yield, %
4 mil. Machine Direction	7	1.008	0.0041	71	17252	8
	8	1.004	0.0041	71	17150	8
	9	0.996	0.0041	70	17215	8
	10	0.994	0.0041	70	17161	8
	11	0.998	0.0041	71	17333	8
Average				71	17222	8
Standard Deviation				1	74	0
4 mil. Transverse Direction	7	1.006	0.0041	64	15622	5
	8	1.008	0.0041	68	16379	6
	10	1.000	0.0041	66	16051	5
	11	0.996	0.0041	65	15874	4
	12	0.988	0.0041	63	15624	5
Average				65	15910	5
Standard Deviation				2	319	1
7 mil. Machine Direction	6	1.004	0.0072	124	17182	10
	8	1.001	0.0072	122	16944	8
	9	1.036	0.0072	126	16900	8
	10	1.005	0.0072	121	16749	8
	11	1.023	0.0072	125	17016	8
Average				124	16958	8
Standard Deviation				2	159	1
7 mil. Transverse Direction	1	1.028	0.0072	121	16333	7
	3	1.010	0.0072	117	16090	6
	4	0.998	0.0072	113	15766	6
	5	1.042	0.0072	118	15761	6
	6	1.028	0.0072	125	16845	7
Average				119	16159	6
Standard Deviation				4	452	1

TEST RESULTS Continued

Tensile Results Continued

Sample	Specimen	Width, in	Thickness, in	Break Strength Force, lbf	Tensile Strength at Break, psi	Ultimate Elongation, %
8 mil. Machine Direction	1	1.019	0.0082	179	21377	159
	3	1.009	0.0082	184	22208	163
	4	0.992	0.0082	181	22204	161
	5	1.030	0.0082	188	22301	167
	6	1.016	0.0082	190	22778	171
Average				184	22174	164
Standard Deviation				5	505	5
8 mil. Transverse Direction	2	0.996	0.0082	257	31442	105
	3	0.990	0.0082	249	30613	90
	4	0.994	0.0082	253	30998	102
	5	1.013	0.0082	261	31416	98
	6	0.988	0.0082	254	31403	98
Average				255	31174	98
Standard Deviation				5	363	5
13 mil. Machine Direction	8	1.088	0.0138	262	16989	168
	9	0.992	0.0138	277	20226	199
	11	0.996	0.0138	281	20472	202
	12	0.971	0.0138	255	19053	145
	13	1.003	0.0138	265	19160	140
Average				268	19180	171
Standard Deviation				11	1377	29
13 mil. Transverse Direction	4	0.996	0.0138	316	22957	222
	7	0.992	0.0138	297	21717	172
	8	0.996	0.0138	300	21818	151
	9	0.998	0.0138	287	20871	136
	10	0.994	0.0138	286	20850	133
Average				297	21643	163
Standard Deviation				12	864	36

TEST RESULTS Continued

Tensile Results Continued

Sample	Specimen	Width, in	Thickness, in	Yield Strength Force, lbf	Yield Strength, psi	Elongation at Yield, %
8 mil. Machine Direction	1	1.019	0.0082	139	16619	7
	3	1.009	0.0082	141	17075	8
	4	0.992	0.0082	139	17146	8
	5	1.030	0.0082	143	16984	7
	6	1.016	0.0082	143	17194	8
Average				141	17004	8
Standard Deviation				2	229	1
8 mil. Transverse Direction	2	0.996	0.0082	127	15557	5
	3	0.990	0.0082	123	15140	4
	4	0.994	0.0082	131	16024	5
	5	1.013	0.0082	131	15714	4
	6	0.988	0.0082	127	15669	4
Average				128	15621	4
Standard Deviation				3	320	1
13 mil. Machine Direction	8	1.088	0.0138	218	14522	21
	9	0.992	0.0138	225	16437	10
	11	0.996	0.0138	230	16764	11
	12	0.971	0.0138	225	16799	10
	13	1.003	0.0138	233	16854	12
Average				226	16275	13
Standard Deviation				6	994	5
13 mil. Transverse Direction	4	0.996	0.0138	216	15751	10
	7	0.992	0.0138	213	15582	8
	8	0.996	0.0138	219	15911	8
	9	0.998	0.0138	217	15758	8
	10	0.994	0.0138	218	15859	8
Average				217	15772	8
Standard Deviation				2	126	1

Some tensile 13 mil machine direction specimens exhibited delamination breaks with two failure points. These specimens were not used in the statistical analysis. All strength calculations were determined using the measured specimen width and nominal thickness without the adhesive, shown above. Measured thicknesses of individual specimens with adhesive is available upon request.

TEST RESULTS Continued

Puncture Results

Sample	Specimen	Puncture Strength, lbf
4 mil	1	60.6
	2	76.6
	3	62.4
	4	62.3
	5	63.4
Average		65.1
Standard Deviation		6.5
7 mil	1	131.5
	2	128.0
	3	92.2
	4	119.7
	6	118.8
Average		118.0
Standard Deviation		15.4
8 mil	1	174.2
	2	167.9
	3	168.6
	4	137.3
	5	118.5
Average		153.3
Standard Deviation		24.2
13 mil	2	214.6
	3	212.8
	4	203.1
	5	207.3
	6	223.5
Average		212.3
Standard Deviation		7.8