MODULE TARP PERFORMANCE IN WEATHERING TESTS

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Abstract

An update to module tarp performance in outdoor weathering and water penetration resistance is provided. A total of 15 months of summer exposure have been accumulated for module tarps that continue to provide moisture resistance. Tarp designs that continue to resist moisture penetration in the outdoor weathering test are PVC coated PET scrim (vinyl), polyethylene film (film), and two polyethylene woven scrim with laminate (woven poly) materials.

Additional tests for mechanical degradation were conducted in a wind tunnel where tarps were subjected to winds up to 50 miles per hour. Preliminary results indicate that "hold down" tension is a critical factor in resisting mechanical damage due to wind motion. Vinyl material, film material, and woven poly material were found to not degrade when secured tightly to the module. However, when secured loosely, the tarp would flap in the wind, and degradation began within 1 hour of exposure. Film and two woven poly materials allowed water penetration, while the vinyl material and one woven poly material allowed little or no water penetration after 1 hour.

Introduction

Research on module tarps has been conducted and continues at Texas A&M University in the Department of Biological and Agricultural Engineering. In prior years, module tarp samples were cut from tarps and tested in standardized test methods in a laboratory setting. The goal of testing has been to evaluate and characterize performance of module tarps over extended storage periods. Tests have focused on UV-light damage due to outdoor exposure and more recently module tarp damage due to wind.

Pinholes and larger holes are formed in module tarp materials with use. The amount of use at which holes begin to form has not been fully quantified. The rule of thumb throughout the industry has been three years of use for all module tarps before rotating inventory and purchasing new tarps. However, based on research conducted, the different materials used in fabricating module tarps show a variance in performance.

Procedures

Module tarp manufacturers/distributors donated 36 new tarps to the project effort. Also, over 60 used tarps have been collected to date from ginners, tarp manufacturers and tarp repair companies. New and used tarps include specimen from seven different manufacturers, encompassing a range of materials, styles, construction, damage level and geographic areas of the U.S. Cotton Belt in which used were obtained. Table 1 presents descriptions of the tarps included in the study. For reasons of confidentiality, the various tarps will be referred to by the code letter indicated. Module tarps fell into one of three types of tarps described by material and construction: (1) PVC coated PET scrim (vinyl), (2) polyethylene film (film), or (3) polyethylene woven scrim with laminate (woven poly).

The tarps were all evaluated using a light box with high output fluorescent lights. Module tarps were characterized according to appearance and damage level. Most new tarps were free of serious defect or damage. Used tarps were divided into four levels of damage based upon pin-hole density and larger hole occurrence. Damage ratings were light, moderate, heavy and abuse. Specimens with varying damage conditions were marked and cut from each tarp. At least 5 samples were taken from each tarp. Each of the new tarps were sampled to allow six replications of outdoor weathering treatment.

The performance of module tarps was based on ability to resist moisture penetration. Two testing standards were identified to evaluate penetration resistance under simulated rainfall and water ponding on surfaces of samples. American Association of Textile Chemists and Colorists (AATCC) standard TM 42-2000 Water Resistance: Impact Penetration Test was used for simulating rainfall. The test apparatus was constructed according to standard specifications, with the exception that the angle of the support surface was set at 15° rather than the specified 45°. This change was made to more closely simulate conditions on cotton modules. With the exception of the support angle, the procedure exactly followed the standard procedure. An amount of 500 mL ± 10 mL of deionized water was poured into a funnel attached to a machined spray head. The water fell 24 inches to the sample with a blotter paper backing. The blotter paper was pre- and post-weighed to determine the water amount that penetrated the sample. Figure 1a shows the rainfall simulation test in practice. The light table used for rating tarp condition is in the background.

Table 1. Description of tarps included in testing.

Tarp Code	Material	Construction (WarpXWeft)	Year/Condition/ (Amount)	Color(s)
A	Poly	Woven (8X10)	2003 new (2) 2000 new (1) 2001 used (2)	Tan/White Tan/White Green/White
B	Poly	Woven (12X12)	no year new (1) 1993 used (1)	Green/Green Yellow/Yellow
C	Vinyl	Woven (8X8)	2003 new (1) 2003 new (1) 2002 new (1) 2002 used (3) 2001 used (1) no year used (1)	Green /White Yellow/White Blue /White Red/White Blue/White Green/White
D	Poly	Film	2003 new (3) 2003 used (5) no year used (2) no year used (4)	Gray/Gray Blue/Blue Gray/Gray Green/Green
E	Poly	Woven	1998 used (2) 1995 used (1) no year (1)	Silver/Black Silver/Black Silver/Black
F	Poly	Woven (14X14)	2002 new (2)	Green/White
G	Poly	Woven (8X9)	2001 new (3)	White/White
H	Poly	Woven (8X10)	2002 new (3) 1996 used (1) 1995 used (1) 1995 used (1) no year used (1)	White/White Green/Black Green/Black Blue/Black Green/Black
I	Poly	Woven (9X12)	2002 new (3) 1991 used (2)	White/White Lt.Blue/Black
J	Poly	Woven (12X12)	2002 new (2) 2002 new (1) 2000 used (1) 1998 used (2) 1995G used (1)	White/White Blue/Black Blue/Black Blue/Black Blue/Black
K	Poly	Woven (14X14)	2002 new (1) 2001 new (2) 1999 used (3) 1999 used (1) 1998 used (2)	Blue/Black Green/White Green/White Blue/Black Green/White
L	Poly	Woven (11.5X9.5)	2003 new (3)	Yellow/White
M	Poly	Woven (15X15)	no year new (1) no year new (1)	Green/White White/White
N	Poly	Woven	no year used (1)	Black/White
O	Poly	Woven (12X9)	2001 new (3)	White/White

Figure 1a) Rainfall simulation in the foreground with light table evaluation in background; b) Tarp specimen in outdoor weathering racks.

For simulating water ponding on the tarp material, the American Society for Testing and Materials (ASTM) standard D 751 – 98 Standard Test Methods for Coated Fabrics, Section 37 Hydrostatic Resistance, Procedure B was followed. The test apparatus was constructed according to standard specifications. This standard could be considered an accelerated test for water ponding on the tarp material, as the hydrostatic head of water maintained over the tarp was one meter. This is a significantly greater head than would be found on a module tarp in the field, however, the greater head allowed a measurable amount of water to be collected in a shorter time period. The procedure deviated from the standard recommendation (recording the time required for the first drop of water to penetrate the sample) in that the tarp specimen was exposed to the hydrostatic head for ten minutes, and the mass of water accumulated was weighed.

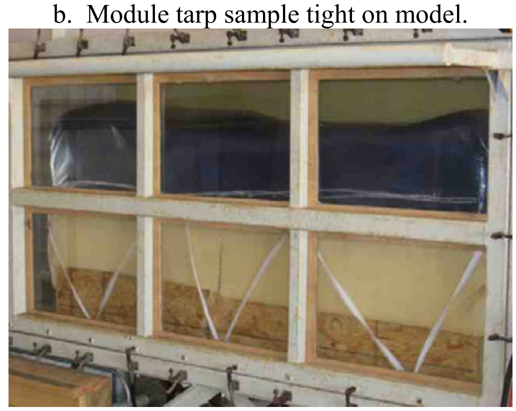
An additional treatment of the tarp specimen was long term weathering. The protocol followed ASTM Designation D 1435-99 Standard Practice for Outdoor Weathering of Plastics. Prior to weathering, the specimen were tested with both the rainfall and hydrostatic head procedures. Samples were mounted onto wood racks. Each sample was backed with lint. The racks were placed outdoors (figure 1b) about 5 miles west of Easterwood Airport, College Station, Texas, (latitude 30° 36´N and longitude 96° 24´W). Temperature, relative humidity and solar radiation were monitored daily by an on-site weather station. Following a three month exposure period, the specimen were removed from the rack and subjected to the rainfall and hydrostatic head tests.

Wind damage is an important degradation source to consider for both Coastal Bend and High Plains regions and little information is available on tarp failure modes due to wind. In order to evaluate wind damage to module tarps, wind tunnel testing was initiated. The USDA-ARS Areawide Pest Management Research Unit in College Station operates a wind tunnel with a 6' x 6' flow field (Figure 2a), and has agreed to allow its use in these studies.

A model module for use in wind tunnel testing was built 5 ft X 7 ft X 3ft and placed in the effective test area of the wind tunnel (Figure 2b). The seven foot dimension represents the width distance across the top of a module. Tarp samples were cut from full-size module tarps and sewn into form-fitted tarps to place on the model for initial testing. Ponding tests were performed on the samples prior to wind tunnel tests.

The samples were secured tightly to the model so that during testing, the tarps puffed up (Figure 2b, but no flapping or whipping occurred. Conditions during the first test began at approximate wind speeds of 35 mph for one hour. A one-hour bucket test as recommended by Willcutt and Mullendore (1987) was performed, showing no water penetration, and thus virtually no pinhole formation.

a. Wind tunnel fan and motor. b. Module tarp sample tight on model.



c. Module tarp loosely tied to model. d. Whipping effect of wind on module tarp.

Figure 2. Module tarp testing in a wind tunnel.

A subsequent wind test was performed with the same tarp sample secured tightly to the model and tested for 3 hours at 35 mph. Again no water penetration occurred. In the third test the sample was secured somewhat looser so that it was allowed to draw up away from the model as in Figure 2c, and whip or flap around (Figure 2d) during a one-hour test. Results of subsequent bucket tests indicated increased pinhole formation due to flapping. Ponding tests were conducted after the wind tunnel and bucket tests were completed. Video segments of the flapping tarp were taken and in slow-motion reveal severe action and force on the tarp materials and construction due to the wind. This process was repeated on different module tarp samples.

Results & Discussion

Due to the range of tarps available and the various conditions found on those tarps, the number of specimen available under each model and condition was variable. As a result, statistical analysis for unbalanced data sets was needed. The Generalized Linear Model (GLM) procedure of the Statistical Analysis Software (SAS) was used to analyze the data. The Duncan Multiple Range test was used to determine those means which were significantly different from the rest. A number of conditions (particularly on the used tarps) were available in only a few specimens. Those are not reported here due to insufficient sample numbers.

Simulated rainfall tests on 1126 new and used tarp specimen were completed. The means for the specimen conditions of new, light, moderate, heavy and abusive use are shown in Figure 3. The mass of water penetrating the tarp increased dramatically with increased use level. Of these five conditions, only the new and light use conditions were not significantly different. The new condition specimen allowed near zero water penetration, while the lightly used tarps only allowed slightly more. This result quantifies the expected result that tarps perform more poorly as the number of holes and defects increase.

Rainfall penetration means were examined within condition classes. Differences in performance were seen between different tarp models within the heavy and moderate use classes. No significant differences between models were found for new or lightly used tarps. The ranking of tarp models in water penetration within these use classes did not show a consistent trend regarding particular models. This is to be expected, as for any model, inclusion in a use class was an indication of the damage that the particular tarp had experienced.

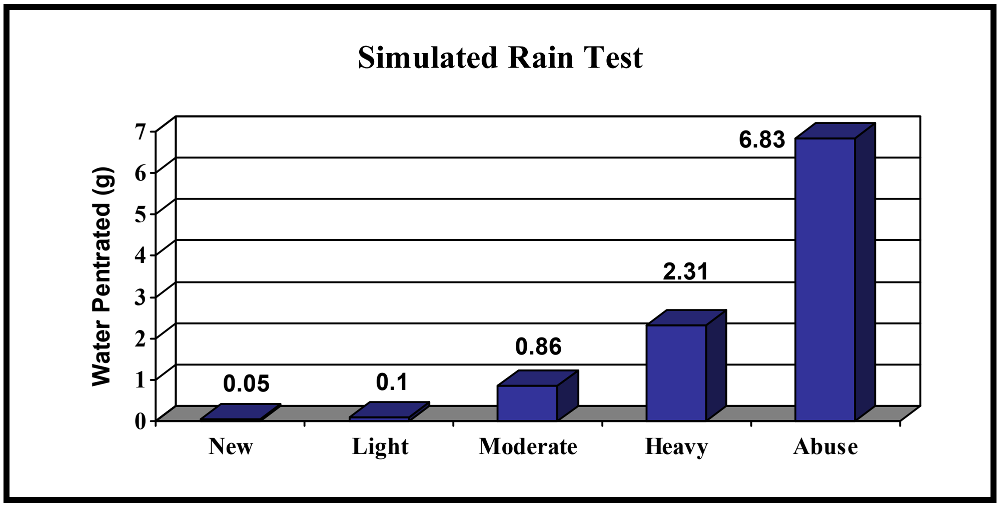


Figure 3. Mean moisture penetration of tarp specimen as a function of damage ratings. The values are the mass of water absorbed on blotter paper placed under the specimen.

Outdoor weathering was conducted from 2003 to 2007, for new module tarp samples. Data are presented for comparison of testing results in Tables 2 and 3. Table 2 shows rate of water penetration in the ponding test following each period of weathering, and Table 3 shows rate of water penetration in the rain test. Meteorological data that were collected included solar radiation shown in MJ/m^2.

Samples accumulated approximately 2,200 MJ/m^2 of solar radiation in the first three month summer period (Table 2 and 3, column S1). Of the eleven module tarp models that were woven poly materials (F, K, M, J, I, B G, H, A, L, and N), four models (F, K, M, and J) resulted in ponded water penetration rates 18.5 g/min or above and were statistically higher than the other seven. These high water penetration rates are considered failures, so models G, K, M and J were removed from further testing. The film material, model D, and vinyl material, model C, along with woven poly models G, H, A, L, and N, all had low rates of water penetration that were not statistically different and remained in the test for another three summer months. Model B was removed from the test, however, due to inadequate number of samples.

During the second summer period (column S2), another 2,100 MJ/m^2 solar radiation was accumulated. Model I resulted in statistically higher water penetration rates, at 2279.4 g/min, compared to other models. Model N had a higher mean rate, however, it was statistically not different than other models due to some samples having low penetration rates. Model I was removed from continued testing due to poor performance, while model N was continued.

The third 3-month, summer period (column S3) provided another 2,100 MJ/m^2 of solar radiation for an accumulated amount of 6,400 MJ/m^2. Model N now showed poor performance in both rain and pond tests at 24.9 and 1000 g/min, respective average rate of penetration. Model N was removed from further testing due to poor performance. Models G, H, D, C, A, and L each performed statistically lower than Model N and continued in further tests.

In the forth summer of testing (column S4), 2,000 MJ/m^2 solar radiation was accumulated for a total of 8,500 MJ/m^2. All models still in the outdoor weathering test performed well in the rain and pond tests. Model A resulted in a statistically higher rate of penetration ponding than models G, H, D, C, and L. However, the means were relatively small rates and successfully prevented water penetration.

Table 2. Water penetration rate through module tarp samples in ponding tests after weathering

		Material	Construction	Ponding Test Results				
				S1	S2	S3	S4	S5
Solar Radiation, (MJ/m^2)				2,200	2,100	2,100	2,000	1,910
Accumulated Solar Radiation, (MJ/m^2)				2,200	4,300	6,400	8,500	10,600
				Average Water Penetration Rate^ (grams of water per minute)				
Tarp Model Code	F^{+}	Plastic	Woven (14x14)	39.1^{a}				
	K^{+}	Plastic	Woven (14x14)	26.1^{b}				
	M^{+}	Plastic	Woven (15x15)	19.7^{b}				
	J^{+}	Plastic	Woven (12x12)	18.5^{b}				
	I^{+}	Plastic	Woven (9x12)	8.2^{c}	2279.4^{a}			
	B$^{\#}$	Plastic	Woven (12x12)	0.8^{c}				
	G	Plastic	Woven (8x9)	0.2^{c}	0.5^{b}	0.5^{c}	0.7^{b}	1.2^{a}
	H	Plastic	Woven (8x10)	0.1^{c}	0.2^{b}	0.3^{c}	0.2^{b}	0.4^{a}
	D	Plastic	Film	0.0^{c}	0.0^{b}	0.0^{c}	0.0^{b}	1063.7^{a}
	C	Vinyl	Woven (8x8)	0.0^{c}	0.0^{b}	0.0^{c}	0.0^{b}	0.0^{a}
	A*	Plastic	Woven (8x10)	0.1^{c}	0.6^{b}	1.3^{b}	3.8^{a}	
	L*	Plastic	Woven (12x9)	0.0^{c}	0.0^{b}	0.0^{c}	0.0^{b}	
	N^{+}*	Plastic	Woven (12x9)	0.0^{c}	174.5^{b}	1000^{a}		

^Values in same column with same letter indicate no significant difference in mean.
$^{+}$Five tarp models were removed from study after Summer 1, 2 or 3, respectively, due to poor performance.
$^{\#}$One tarp model was removed from study after Summer 1 due to inadequate number of samples.
*Three tarp models added to the study during the Summer 2 period.

Table 3. Water penetration rate through module tarp samples in rain tests after weathering

		Material	Construction	Rain Test Results				
				S1	S2	S3	S4	S5
Solar Radiation, (MJ/m^2)				2,200	2,100	2,100	2,000	1,910
Accumulated Solar Radiation, (MJ/m^2)				2,200	4,300	6,400	8,500	10,600
				Average Water Penetration Rate^ (grams of water per minute)				
Tarp Model Code	F^{+}	Plastic	Woven (14x14)	0.3^{b}				
	K^{+}	Plastic	Woven (14x14)	7.6^{a}				
	M^{+}	Plastic	Woven (15x15)	0.0^{b}				
	J^{+}	Plastic	Woven (12x12)	0.2^{b}				
	I^{+}	Plastic	Woven (9x12)	0.0^{b}	7.7^{a}			
	B$^{\#}$	Plastic	Woven (12x12)	0.0^{b}				
	G	Plastic	Woven (8x9)	0.0^{b}	0.0^{b}	0.0^{b}	0.0^{a}	0.0^{b}
	H	Plastic	Woven (8x10)	0.0^{b}	0.0^{b}	0.0^{b}	0.0^{a}	13.8^{a}
	D	Plastic	Film	0.0^{b}	0.0^{b}	0.0^{b}	0.0^{a}	0.0^{b}
	C	Vinyl	Woven (8x8)	0.0^{b}	0.0^{b}	0.0^{b}	0.0^{a}	0.0^{b}
	A*	Plastic	Woven (8x10)	0.0^{b}	0.1^{b}	0.0^{b}	4.5^{a}	
	L*	Plastic	Woven (12x9)	0.0^{b}	0.0^{b}	0.0^{b}	5.1^{a}	
	N^{+}*	Plastic	Woven (12x9)	0.0^{b}	0.2^{b}	24.9^{a}		

^Values in same column with same letter indicate no significant difference in men.
$^{+}$Five tarp models were removed from study after Summer 1, 2 or 3, respectively, due to poor performance.
$^{\#}$One tarp model was removed from study after Summer 1 due to inadequate number of samples.
*Three tarp models added to the study during the Summer 2 period.

Models A and L, while continuing to perform with low rates of water penetration, have only been available to accumulate four years of solar radiation and have not been tested for five years.

The fifth summer period (column S5) included another three months of solar radiation accumulation for a total of 10,600 MJ/m^2. Model D resulted in higher average rate of water penetration in the pond test than models G, H, and C, however, was statistically not different. Again this is due to some model D samples having high rates and others having low rates. Model D samples had low rain test results and were intact during rain testing, but when placed in the accelerated pond test with 1 meter of water head, some samples split and resulted in failures. Model D was stopped from further testing.

As previously mentioned, the outdoor weathering tests remove wind as a mode of damage to tarps because the samples were pulled tight in the racks and not allowed to move. Wind is a factor in tarp degradation and has not been quantified. Our testing in the wind tunnel is at the beginning stages and preliminary.

Average and standard deviation of water penetration rate and standard deviations are displayed in Table 4 only for models tested thus far. All tarp models tested, C, D, I, N, and H, allowed no significant water penetration before the wind testing. Even after testing the tarps pulled tightly and secured so that no flapping occurred, all tarps allowed no significant water penetration. However, after only 1 hour of wind tunnel testing in which the tarps were allowed to flap due to being loosely secured to the module, model D failed and models I and N resulted in significant water penetration rates of 125.9 and 98.0 g/min, respectively. Models C and H resulted in little if any water penetration.

Table 4. Ponding test results before and after wind tunnel testing.

	Rate of Water Penetration in Ponding Test			
Tarp	Before Wind		After 1 hr Wind, Loosely Tied	
	Avg, g/min	StdDev, g/min	Avg, g/min	StdDev, g/min
Vinyl C	0.0	0.0	0.0	0.0
Film D	0.0	0.0	Failed	-
Woven Poly I	0.0	0.0	125.9	194.6
Woven Poly N	0.1	0.1	98.0	201.7
Woven Poly H	1.4	2.0	4.8	4.2

Application

Thirteen module tarp models were tested in outdoor weathering. Six models prevented water penetration in rain and pond tests for four and five years, with some models still viable for further years of testing. The tests were applied over 15 months of summer conditions in Texas where solar radiation averaged 2,100 MJ/m^2, temperature range averaged 20.5 – 35.5°C (69 – 96°F), and rainfall averaged 230 mm (9.2 in). A typical winter in the same area produced average solar radiation of 1,100 MJ/m^2, average temperature range 4.5 – 20.5°C (40 – 68°F), and average rainfall 220 mm (8.8 in). Assuming similar solar radiation amounts for all areas of cotton production, knowing that there will be some differences, an equivalent use factor could be developed.

Not considering wind, a 3 month summer of our test results may equal 6 winter months, or 4.5 fall months, or 4.5 spring months. These factors could be used to determine the length of time a tarp may be used with adequate performance in outdoor weathering at different time in Texas ginning seasons. Our experience in testing was for 15 months during summer periods. This would equate to 5 to 6 ginning seasons for a Texas Gulf Coast season when the gin operates July through September. It would also equal 7.5 ginning seasons for a Texas High Plains season when the gin operates October through December, or about 4 ginning seasons for an October through March season.

Conclusion

Six models of module tarps performed in outdoor weathering testing for 12 to 15 summer months and allowed little or no water penetration. These models included woven poly materials, vinyl materials, and film materials. Two woven poly materials performed marginally with 3 to 6 summer months of adequate water penetration prevention. Four woven poly materials performed poorly with less than 3 months of water penetration prevention.

Preliminary results show vinyl material prevented water penetration in the ponding test after experiencing winds 35 to 50 mph, fitted tight to the module as well as 50 mph winds fitted loosely to the module and flapping rigorously. The film material prevented water penetration during the bucket test with winds up to 40 mph and fitted tight to the module. However, when the film material was fitted loosely to the module and was allowed to flap vigorously in 35 to 50 mph winds, the tarp failed from one corner to the opposite corner within 1 hour. Woven poly materials prevented water penetration in bucket testing with winds up to 50 mph and fitted tight to the module. Woven poly materials, when fitted loosely to the module and allowed to flap, had varying performance in ponding tests.

Acknowledgements

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