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PERFORMANCE OF MODULE COVERS IN RESISTING MOISTURE PENETRATION

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Abstract

Module covers are one part of the module system that when correctly managed ensure cotton lint and seed are protected from rainfall and other environmental factors. New and used module covers currently used in the cotton industry were subjected to standard test methods for water impact (to simulate rainfall) and hydrostatic resistance (to simulate ponding of water). Treatments to new covers included outdoor weathering and pinhole punctures. Used covers were categorized as light damage, moderate damage, heavy damage and abusive damage as determined by visual inspection. Results indicate that as damage level was more severe, water that penetrated the cover material during testing increased. The outdoor weathering treatment results showed that as woven polyolefin material increased in number of tape intersections per square inch, the amount of water penetrating the cover increased. The woven vinyl and the film polyolefin materials allowed zero water to penetrate after weathering. The pinhole treatment results indicate that film polyolefin material allowed a significantly greater amount of water to penetrate the specimen compared to the woven polyolefin and woven vinyl materials. Evaluations at Texas gins revealed that water ponded on 50% of modules after rain events due to uneven module surfaces. Ponding is likely to allow more water to enter the seed cotton than rainfall. Therefore, the module system as a whole is important, specifically the formation of modules having a crowned surface, to prevent ponding of water and allow rainfall to run off of the module cover.

Background

The cotton industry incurs poor lint and seed grades each year in any given geographical area due to rainfall events during and after harvest time. Replacing the use of cotton trailers with the module system has reduced the amount of cotton losses from rainfall, especially due to hurricanes and severe storms, and therefore, increased returns to producers. For the module system to maintain cotton quality during storage, several key items must be in place: a well-built module, a durable module cover and a proper area for storing the module. If any of these components are lacking, moisture or other degrading factors can cause lint and seed damage within the module.

Various cotton industry educational brochures spell out recommendations for building and covering modules. The problem lies in that educational brochures only go so far in ensuring a successful module system. Producers and custom harvest crews must follow the recommendations. The American Society of Agricultural Engineers (ASAE) has developed a standard, ANSI/ASAE S392.1, that details module builder dimensions and cover specifications. The standard has been updated over the past decades; however, in the latest draft standard, the specification for module covers was deleted. The module cover section of the standard only described canvas covers, an obsolete design. Most covers used today are manufactured from synthetic materials, usually polypropylene, polyethylene, vinyl or a combination of the three.

In addition to education efforts, the cotton industry has requested research to improve the quality preservation abilities of the cotton module transport and storage system. The following information is provided as a result of research conducted at the Department of Biological and Agricultural Engineering at Texas A&M University and funded by 1) Texas Food and Fiber Commission, 2) The Cotton Foundation and 3) Cotton Incorporated – Texas State Support Committee. Research conducted during the first year of the on-going, three-year project focused on the following three objectives:

1. evaluating the performance of new and worn module cover materials in resisting moisture penetration,
2. developing and evaluating an inexpensive module shape monitor that can provide feedback on shape and density to module builder operators, and
3. initiating the establishment of a research data base that could form the basis for an updated standard for module cover design and performance, and an engineering practice on the construction of cotton modules.

This paper will focus on the first objective while the second objective is covered in the 2004 Beltwide paper entitled, "Viscoelastic Properties of Seed Cotton and their Impact on Module Shape and Density," authored by Robert G. Hardin, Stephen W. Searcy and Shay L. Simpson in the Cotton Engineering-Systems Conference.

Module Cover Performance

Previous records from a National Cotton Council (NCC) study on module covers were reviewed. Records were found pertaining to tensile strength, elongation, tear strength and seam strength for covers manufactured from 1991 to 1992 and may prove useful in future aspects of this study.

Contacts were initiated with module cover manufacturers regarding the project, and have led to donations of 35 new covers to the project effort. Also, 48 used covers have been collected to date from ginners, cover manufacturers and cover repair companies. New and used covers 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. Table 1 presents descriptions of the covers included in the study. For reasons of confidentiality, the various covers will be referred to by the code letter indicated.

Procedures

The covers were all evaluated using a light box with high output fluorescent lights. Module covers were characterized according to appearance and damage level. Most new covers were free of serious defect or damage. Used covers were divided into four levels of damage based upon pin-hole density and larger hole occurrence.

Specimens with varying damage conditions were marked and cut from each cover. The condition classifications are given in Table 2. At least 5 samples were taken from each cover for every condition found unless that condition was not available in five locations. Corners were sampled only at a maximum of four per cover. Each of the new covers also was sampled to allow five replications of induced damage treatments (see Table 2). Needle treatments were made by punching a needle one time through a sample to simulate a small pin-hole similar to what stalks, bracts and other cotton plant residue might create in covers.

The performance of module covers 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 1 shows the rainfall simulation test in practice. The light table used for rating cover condition is in the background.

For simulating water ponding on the cover 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 cover material, as the hydrostatic head of water maintained over the cover was one meter. This is a significantly greater head than would be found on a module cover 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 cover specimen was exposed to the hydrostatic head for ten minutes, and the mass of water accumulated was weighed. Figure 2 shows a drop of water penetrating the woven cover specimen.

Three treatments were performed on the new cover specimen and subjected to the two tests. Two of the treatments consisted of holes made deliberately using needles. A fine needle with a 0.33 mm diameter and a medium needle with a 0.79 mm diameter were used to punch one hole through each specimen from new covers. The specimen were then oriented in the test instruments such that the water would contact the specimen at the pinhole.

A third treatment of the cover specimen was long term weathering. A limited evaluation of cover performance when exposed to prolonged sunlight and outdoor environment was established. This test was possible due to adequate numbers of new cover specimens gathered. 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. Fifty-six new cover samples, 2 cotton bale bagging samples and 2 clear film samples were mounted onto wood racks. Each sample was backed with seed cotton held in place by wire screen. The racks were placed outdoors (figure 3) about 5 miles west of Easterwood Airport, College Station, Texas, (latitude 30° 36´N and longitude 96° 24´W), on June 20, 2003. Temperature, relative humidity and solar radiation were monitored daily by an on-site weather station. Following a three month exposure period, in which 2135 MJ/m^2 solar radiant energy were recorded, the specimen were removed from the rack and subjected to the rainfall and hydrostatic head tests a second time.

Results and Discussion

Due to the range of covers available and the various conditions found on those covers, 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 covers) were available in only a few specimen. Those are not reported here due to insufficient sample numbers.

Simulated rainfall tests on 1126 new and used cover specimen were completed. The means for the specimen conditions of new, light, moderate, heavy and abusive use are shown in figure 4. The mass of water penetrating the cover 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 covers only allowed slightly more. This result quantifies the expected result that covers 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 cover models within the heavy and moderate use classes. No significant differences between models were found for new or lightly used covers. The ranking of cover 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 cover had experienced. With the limited number of covers available for examination, no conclusions can be drawn regarding the likelihood of any model to sustain damage with use.

The hydrostatic head test was performed only on the 474 specimen from the new covers and those that were used in the weathering test. Specimen from used covers remain to be tested. The analysis of variance for new covers showed no significant difference between covers in mean water penetration. However, this result is somewhat deceiving, as the performance of the various samples from a given cover model could be quite variable. For example, covers C, D and L uniformly had 0.0 g of water penetration, while model A had sample results that varied from 0.0 to 100.9 g. This wide variability between sample performance for covers of the same model and manufacturer was common.

As expected, creating a pinhole in the specimen resulted in significantly greater water penetration. However, the performance of the covers varied significantly. Table 3 shows the means for each cover model for both the fine and medium needle pinholes. The letters indicate those covers that are significantly different as determined by the Duncan's Multiple Range Test. While relative rank varies in these two tests, cover D allowed significantly more penetration than the others.

The cover materials that were weathered for three months showed widely ranging performance in the rainfall and hydrostatic head tests. Table 4 shows the performance of the materials in these two tests. When tested prior to weathering, the different covers showed no significant differences in performance and very little water penetration. While these tests showed varying levels of resistance to weathering damage, there were differences detected between the replications of a given cover. For example, cover K has two covers of a green/white coloring and one with blue/black. The green/white covers allowed enough water to penetrate to overflow the catch cup, while the blue/black specimen averaged only 0.1 g of water. The hydrostatic head test was clearly a more rigorous test than the rainfall, and although a head of one meter is unrealistic for actual practice, some of the covers were successful in resisting penetration by that high pressure following the weathering period.

Cover construction appears to be a significant factor in resistance to moisture penetration after weathering in the ponding test. Table 5 displays values of water penetration for the various polyolefin materials of a woven construction. The "warp versus weft" construction indicates the number of tapes per inch that run in the machine versus cross direction, respectively, of the scrim or base material. As the warp vs. weft construction increases, the water weight penetrating the material increases from 1.1 to 326.1 g. Note that as the number of tapes per square inch increases, the intersections where tapes cross increase. These intersections are points where water could "work through" any degradation of coating and penetrate the cover.

Water penetration testing continues, and additional data will allow a greater discrimination of performance between different covers. However, several observations can be made from the available data. There are significant differences between the cover models in their ability to resist water penetration following weathering. Within a given model of cover, there is considerable difference in the performance of individual covers. It was noted that the color of the cover can result in dramatically different performance. Even between specimen from the same cover, there can be widely ranging amounts of water penetration. These results have been shared with module cover manufacturers to gain their assistance in understanding these differences.

Module Shape

Since module shape determines whether water will pond on the tops of modules or run off, it is important to characterize the suitability of module shapes as created by producers and custom harvest crews. Therefore cotton gins were visited during the 2003 ginning season, and observations were made of the condition of modules stored in the module storage lot. Observations were made from each end of a module, and included a determination of whether the cover showed evidence of having water ponded on the surface. For some covers, standing water was recorded. In other situations, a residue ring in a depression was used as an indicator that water had been standing at some point in the immediate past. Whenever possible, gins were visited shortly after a rainfall. For each module the cover ponding status was assigned, the module number recorded and the characteristics of the cover on the module were recorded. The module numbers will be used to obtain the lint grades for the cotton from each module. Future analyses will examine the relationship between cover condition, ponded water and the lint grades.

Studies were performed at six gins in Texas to determine the module shape characteristics of current practices and cover type variability. Observations were recorded at one Corpus Christi area gin, two Gulf Coast area gins, two Brazos bottom area gins and one El Paso area gin. The module shape data gathered indicated that on average, 50% of all modules observed developed an area that ponded water when rainfall occurred (see Table 6). Clearly the need for an improved system of module formation is justified.

Conclusions

Results from the first year of this project must be considered preliminary. However, several significant observations can be made from the first year of data. The observation of modules stored at gin yards across Texas indicates that approximately half the modules made in 2003 were formed in a manner that resulted in ponding of water on top of the module. Under such a high probability of water collecting on top of the modules, the importance of using covers that will resist the penetration of water is clear. Unfortunately, the performance of the tested covers seems to indicate that many covers after they have been used on modules are unlikely to adequately protect the cotton stored in the module from exposure to moisture. The weathering test for cover specimen dramatically demonstrated that the performance of covers is widely varying, both between models sold by different manufacturers and within covers of the same model. Some covers performed in an excellent manner for all tested specimen and others had several samples that performed well while one or two would allow greater water penetration.

The importance of a cover that resists moisture penetration can be seen in the following example. Using the mean rainfall simulation results for new and used covers, estimates were made of the amount of water that would enter a module. The entire surface of the cover was assumed to have the same penetration resistance during a four hour rainfall event that was sufficiently intense to maintain a sheet of water on the surface of the cover. This assumes no ponding on the cover, but only a thin layer of water running off of the cover. The rainfall simulation lasts for approximately 30 seconds, so the amount of water penetrating the cover was calculated for the assumed storm period. The assumption was also made that the added moisture will be retained in the top 12 inch layer of the module. Table 7 shows the results for the different cover classes. New and lightly used covers will maintain the seed cotton moisture content within a safe range, but covers with greater levels of damage will result in very wet seed cotton that will cause problems for ginning and likely result in lower lint grades.

Future Work

Much of the research described here is still in progress and will continue in the second year of the planned three year project. The proposed work for the next fiscal year includes the following activities.

- Examination of the various modes of cover defect formation. Breakdown by UV-light, cracking during storage, puncture by sticks or burrs and other conditions are anticipated to result in formation of pinholes.
- Improvement of module formation. Operator feedback systems will be developed and used during cotton harvest under close supervision of project personnel. Shape characterization of module top surface topography will be modeled and evaluated for areas of potential water ponding. Analysis will be performed to determine if there are differences in water ponding potential as a result of using the feedback monitor.
- Evaluation of shape and moisture resistance interactions. Mini-modules will be created with three profiles ranging from flat to peaked, and will be covered with specimen known to have light densities of pinhole defects. Samples taken for moisture determination will be pulled from regions under known pinhole locations.

For project year 2, the project was expanded to include two additional objectives as follows

1. Formulate a minimum of three practical scenarios for a new seed cotton handling, storage and ginning system that would result in extended ginning seasons and reductions in production costs. The issues addressed would include (1) the optimum gin size (ginning rate) (2) optimum ginning season, (3) maximize energy savings (operating off-peak), (4) maximize labor savings, (5) minimize insurance costs, and (6) minimize gin equipment maintenance costs. The evaluations will be made using Monte Carlo simulations; and
2. Formulate a feasible, module transport system that could be implemented at a Texas location with the gin service area expanded to 100 and 150 miles.
   a. Study use of semi-tractor trailers (STT), or other system, for moving seed cotton modules from the farm to long-term storage locations near a gin with simulations.
   b. Develop a method of loading and unloading seed cotton modules into STT, or other system, and demonstrate the feasibility of this method on model systems.

These objectives are introduced in the 2004 Beltwide paper, “Systems Analysis of Ginning Seasons and Seed Cotton Transport,” authored by Shay L. Simpson, Calvin B. Parnell, Jr., and Stephen W. Searcy, found in the Ginning Conference section.

Acknowledgements

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Table 1. Description of covers included in testing.

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

Table 2. Conditions and treatments of module cover samples.

Condition Types	Treatments to New Cover Samples
New	None
New – Defect or Crack	Fine Needle (0.33 mm)
Light Damage	Medium Needle (0.79 mm)
Moderate Damage	Outdoor Weathering
Heavy Damage	
Abusive Damage	
Seam	
Corner	
Pinhole	

Table 3. Water penetration with artificial pinholes in ponding test.

Fine Needle Pinhole			Medium Needle Pinhole		
Cover	Mean (g)	Duncan Grouping	Cover	Mean (g)	Duncan Grouping
D	54.2	a	D	252.4	a
H	14.5	b	A	38.5	b
G	12.5	b c	G	37.5	b
A	8.7	b c d	K	35.4	b
K	6.9	b c d	L	31.7	b c
M	5.3	c d	H	30.7	b c
F	4.8	c d	M	17.4	b c d
L	3.6	d	B	15.1	b c d
B	3.1	d	F	12.8	b c d
J	2.5	d	I	8.7	c d
I	2.2	d	C	3.8	d
C	0.7	d	J	3.7	d

Table 4. Water penetration performance after weathering.

Hydrostatic Head			Rainfall Simulation		
Cover	Mean (g)	Duncan Grouping	Cover	Mean (g)	Duncan Grouping
F	391.3	a	K	3.8	a
K	260.9	b	F	0.2	b
M	197.0	b	J	0.1	b
J	185.3	b	H	0.0	b
I	81.5	c	G	0.0	b
B	8.1	c	I	0.0	b
G	1.6	c	C	0.0	b
H	1.1	c	M	0.0	b
D	0.0	c	D	0.0	b
C	0.0	c	B	0.0	b

Table 5. Water penetration performance after weathering grouped by construction.

Hydrostatic Head		
Tapes per sq. in.	Mean (g)	Duncan Grouping
14x14	326.1	a
15x15	198.0	b
12x12	114.5	b c
9x12	81.5	c d
8x9	1.6	d
8x10	1.1	d

Table 6. Observations of module shape and cover made at Texas gins.

Gin	Total Modules Observed	% Ponded*	Module Cover Range of Years	Rain Event
CC1	297	47	93, 95, 98-00, 02-03	5 days prior
G1	66	47	02	Same day
G2	57	44	95, 98, 00	Same day
BB1	91	65	92, 94-96, 99	1 day prior
BB2	93	47	90-94, 96, 00-02	5 days prior
EP1	42	57*	90-01	No rain
All	646	50	90-03	

* % Ponded was a combination of actual water ponded and depressed areas likely to hold water.

Table 7. Estimated amount of water penetrating module covers.

	Abusive Use	Heavy Use	Moderate Use	Light Use	New
Grams of water penetrating cover 6 inch X 9 inch surface area in a 30 second period =	6.8	2.3	0.86	0.1	0.05
Grams water penetrating cover over 8 X 32 ft. surface area in a 4 hour period =	2,230,000	754,000	282,000	32,800	16,400
Pounds water penetrating cover over 8 X 32 foot surface area in 4 hours =	4,910	1,660	621	72.2	36.1
Percent moisture content of top 1 foot of module (assume initial 10% MC)=	63	39	23	11	10

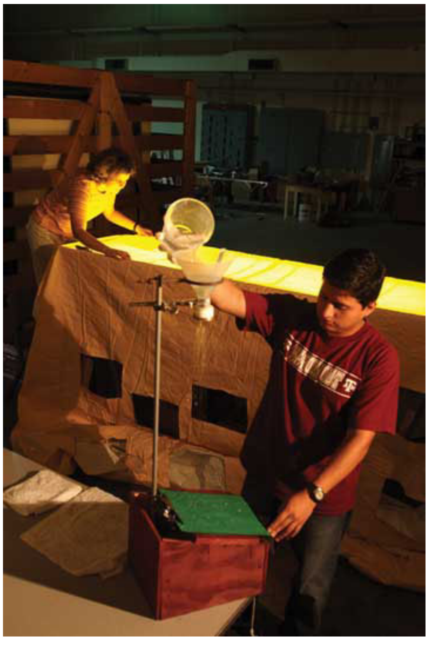

Figure 1. Rainfall simulation in the foreground and light table evaluation in the background.

Figure 2. Ponding test simulation.

Figure 3. Specimen in outdoor weathering racks.

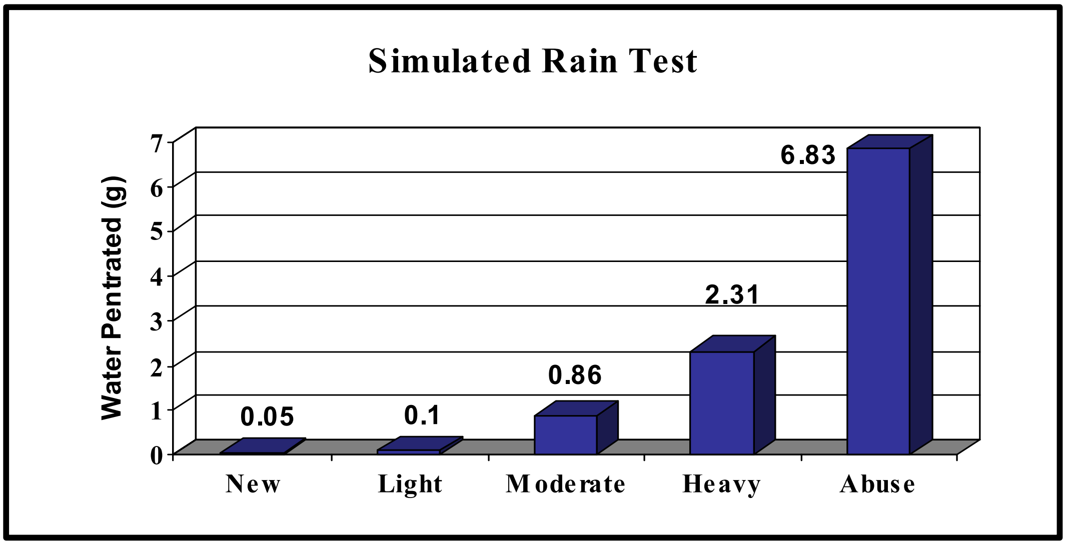

Figure 4. Mean moisture penetration of cover specimen as a function of damage ratings. The values are the mass of water absorbed on plotter paper place under the specimen.