Bale Weight Changes Related to Bale Bagging – Testing and Modeling

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Abstract. Universal Density cotton bales were formed with relatively dry lint, covered with different types of bale bagging materials, and the bales stored in a humid environment for more than 2 months. The bale coverings included coated woven polypropylene with micro-perf holes, linear low density polyethylene film with different hole patterns, woven cotton, woven burlap, and no bale bagging. The bales were weighed periodically during storage. The bale weights were modeled with a nonlinear model exponential in time. Different bales in the same bagging type changed weight consistent with the models. The rate of bale weight change obtained from the regression was used to calculate a half time to equilibrium, in days, for each bagging type. This half time number will allow simplified communication of the effect bale bagging has on the rate of change of cotton bale weight during storage.

Keywords. Cotton, Cotton Bale, Bale Bagging, Moisture Content
Introduction

Standard cotton bales weigh approximately 226 kg (500 lb.) in US commerce and are covered with bagging to protect them during transportation and storage. Individual bagging designs are reviewed and approved for use by the Joint Cotton Industry Bale Packaging Committee (JCIBPC) coordinated by the National Cotton Council. For a particular bagging design to be accepted for use by the US industry it must be approved by representatives from cotton farmers, ginners, cotton warehousing, cotton merchants, and mills. These segments sometimes have different interests, the farmers and ginners have to purchase the bags and would prefer minimum price. The warehousemen have to handle the bales, often multiple times, and would prefer durable bags so that they do not have to repair them. The mill operators want bags which have protected the cotton from contamination which are also easy to handle and recycle.

Cotton is sold by weight without regard to moisture content (mc). Years ago burlap bagging, which was relatively permeable to moisture, was used and the bales were not fully covered. With this covering design the US cotton bales typically came to equilibrium with ambient conditions relatively rapidly while being stored in warehouses located in humid areas during winter months before being spun in mills located in Virginia or North Carolina. In addition to the change in bale weight affecting the total price, the higher mc cotton fiber was stronger and better able to resist damage during the cleaning and spinning processes at the mill. More recently the JCIBPC promoted fully covering bales for cleaner cotton at the mills and woven polypropylene (WPP) was adopted in many cases for its price, light weight, and strength. Anthony (1982) showed that these bags were as permeable to moisture as were the burlap bags. However, when the WPP bags were cut, usually in bale sampling or handling, they released fibers which could become entangled with the cotton fiber. So, the JCIBPC called for coating the bags to contain loose fibers. The coating significantly reduced moisture permeability so the coatings were applied in strips or holes were made in the coatings which improved the permeability (Anthony and Herber, 1991). But in order to better control possible loose fibers created in accidental damage during storage and handling the current standard calls for complete coating of the WPP bags with plastic.

More recently bags made from linear low density polyethylene (LLDPE) film have increasingly been used, mostly because of price. These bags are much less permeable to moisture (Anthony, 1982; Anthony and Herber, 1991) and lose strength when holes are made in them. LLDPE bags are popular without holes, however, the JCIBPC is insisting on examining LLDPE bags with improved permeability achieved through various hole sizes and patterns.

Byler and Anthony (2008) showed that the weight change of different bales covered with the same material was consistent and could be modeled. They showed that the weight change of bales with different currently used bagging varied considerably.

The moisture ratio has often been used when products are studied with changing moisture content but assuming the weight of the dry matter in bales does not change when fiber mc changes the moisture ratio is equal to the bale weight ratio, WR, defined as:

\[ WR = \frac{(W(t) - EW)}{(W(0) - EW)} \]  \hspace{1cm} (1)

where

\[ W(t) = \text{the bale weight at time}=t \]
\[ EW = \text{the equilibrium bale weight, and} \]
\[ W(0) = \text{the bale weight at time}=0 \]

Many agricultural researchers have used the model:

\[ \text{Moisture ratio} = \exp(-b*t) \]  \hspace{1cm} (2)

where \( b = \text{a drying constant with units of time}^{-1}. \) Equations 1 and 2 can be combined and rearranged as:

\[ W(t) = (W(0) - EW) \cdot \exp(-b*t) + EW. \]  \hspace{1cm} (3)

If data were collected for bale weight over time nonlinear regression can fit the data with the model:

\[ W(t) = a \cdot \exp(-b*t) + c \]  \hspace{1cm} (4)

where \( a, b, c = \text{parameters chosen by regression} \)

The parameter \( c \) would be the equilibrium bale weight, \( b \) is the weight change coefficient related to time, and the parameter \( a \) represents the total bale weight change. Fitting equation 4 to data is fairly simple and the model allows bales of different original weights, different total weight change, and bale equilibrium weight to be normalized so that they can be compared more easily. The model would not be expected to fit the data well at small time, the time it takes for the first 5 to 10% of the total weight change. If the model fits the data well it would not be necessary to collect data until the bale reaches equilibrium but the equilibrium bale weight could be projected from the data. The decaying exponential model is common in engineering work and has many useful properties including that the period of time for the weight to change from the original to half the original would be the same no matter when on the curve the measurement started. This time period for half of the bale weight change to occur could be used as an indicator of speed of bale weight change.

Byler and Anthony (2008) measured the weight change properties of certain bale bagging listed in Table 1. In addition, the time for half of the weight change to occur based on the model is listed. The data for the bales with no bagging has been revised after further analysis of additional data obtained by exposing the bales to the study conditions for a longer period of time resulting in an increase in the estimated half time to equilibrium from 10 days to 13 days. This study demonstrated the substantial difference between bales with no bagging, 13 days; with strip coated WPP (no longer accepted), 30 days; and with fully coated WPP bagging, 64 days. The bale weight half time in days is a simple and valuable way of ranking cotton bale bagging. Use of this number would be a relatively simple way to understand and communicate a relatively complex issue, which is important to many involved in the marketing of cotton bales. Based on the half time to equilibrium it would take a bale in a fully coated WPP bag about 192 days, or over 6 months, to change the same proportion as a bare bale would change in 39 days.
Table 1. Cotton bale bagging ID, weight change coefficient from equation 4, and half time to equilibrium for increasing bale weights.

<table>
<thead>
<tr>
<th>Bagging ID</th>
<th>Coefficient b (days(^{-1}))</th>
<th>Half time to equilibrium (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPP fully coated, approved for use in 2003, AMOCO</td>
<td>0.0108</td>
<td>64</td>
</tr>
<tr>
<td>LLDPE with pin holes on grid, FlexSol</td>
<td>0.0148</td>
<td>47</td>
</tr>
<tr>
<td>LLDPE pin holes in stripes, FlexSol</td>
<td>0.0152</td>
<td>46</td>
</tr>
<tr>
<td>WPP with air release holes, Intertape Polymer Group</td>
<td>0.0159</td>
<td>44</td>
</tr>
<tr>
<td>WPP with pin holes, 2003 test program, AMOCO</td>
<td>0.0201</td>
<td>34</td>
</tr>
<tr>
<td>WPP strip coated, AMOCO</td>
<td>0.0228</td>
<td>30</td>
</tr>
<tr>
<td>Bare</td>
<td>0.0527</td>
<td>13</td>
</tr>
</tbody>
</table>

The purpose of the overall project was to examine the weight change of cotton bales with different bagging related to moisture changes caused by ambient conditions. Bagging including bare bales, materials with high permeability, materials with low permeability, and six LLDPE bags with controlled holes were included in the current test. These data were then modeled using a single term exponential with time.

**Materials and Methods**

The bales used in this study were ginned especially for the study with drying. They were from picked cotton with typical pre-cleaning of tower dryer, cylinder cleaner, stick machine, second tower drier, then cylinder cleaner. They were ginned with a Continental Eagle gin stand followed by one lint cleaner. The bales were stored in a chamber which was maintained at 24°C (75°F) and 85% relative humidity. Three types of bagging were used for each category of high permeability and low permeability with two bales per bagging type, Table 2. The bales were placed in the controlled environment within hours of ginning and each was weighed periodically during the storage to create a data set of bale weights over time as the bales gained weight. Data were collected for the bales with high permeability bagging over a period of 69 days and over a 155 day period for the bags with low permeability. The data collection period covered 63 days for the LLDPE bags with holes intentionally made in them. Figure 1 shows one of the bales on the scale used to weigh the bales.

The bagging used in the portion of the study of bags with holes intentionally punched in them was from bags originally prepared for commercial use. Half of the holes were covered with plastic tape to obtain the bags marked as having one hole per unit area. The holes in this bag, after half of the holes were covered, were 54 cm apart around the width of the bag in rows 64 cm apart along the length of the bag. This 3456 cm\(^2\) was the unit area used for additional calculations. All holes were 1.1 cm in diameter (3/8 in). The bags marked with two holes per unit area were as distributed by the manufacturer. Additional holes were made with a punch to get three, four, five and six holes per unit area. The holes were distributed as evenly as practical using an added row between the original rows resulting in rows 32 cm apart for the
higher hole density. All holes were examined to be certain that the plastic was completely removed from the bag. One bale was placed in each bag and data were recorded.

Table 2. Bale bagging included in the study.

<table>
<thead>
<tr>
<th>Study Part</th>
<th>Bagging ID used</th>
<th>Description of bagging</th>
<th>Bale numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>High permeability</td>
<td>Bare</td>
<td>Bare bale, no bagging</td>
<td>2293, 2294</td>
</tr>
<tr>
<td>High permeability</td>
<td>Cotton</td>
<td>Woven cotton, approved for use in 2007</td>
<td>2291, 2292</td>
</tr>
<tr>
<td>High permeability</td>
<td>Burlap</td>
<td>Woven burlap, approved for use in 2007</td>
<td>2287, 2288</td>
</tr>
<tr>
<td>Low permeability</td>
<td>Lspiral</td>
<td>Woven polypropylene, fully coated, spiral sewn with uncoated seam, 1000 D, 8x8 weave, micro-perfed, Langston brand, approved for use in 2007</td>
<td>2296, 2297</td>
</tr>
<tr>
<td>Low permeability</td>
<td>Lsmless</td>
<td>Woven polypropylene, fully coated, seamless, 1000 D, 8x8 weave, micro-perfed, Langston brand, experimental</td>
<td>2298, 2299</td>
</tr>
<tr>
<td>Low permeability</td>
<td>LLDPE</td>
<td>LLDPE with no holes added to bag, Lone Star brand</td>
<td>2300, 2301</td>
</tr>
<tr>
<td>LLDPE with punched holes</td>
<td>LLDPEpunched</td>
<td>LLDPE originally as approved for use in 2007, FlexSol brand, modified as described</td>
<td>2319-2324</td>
</tr>
</tbody>
</table>
The bale weight data were modeled similarly for the three parts using equation 4. The bale weight data starting with day 5 were included in the regression. The SAS (2003) procedure NLIN, a program for nonlinear regression, was used to fit the model to the data with 3 parameters for each bale. Then the model was simplified by considering only one b parameter for each bagging type. Next models were considered which allowed for the same percentage weight change for all bales in the same batch but allowing for different final bale weights. This model would apply if the initial and final lint moisture contents were the same for all bales but a different amount of lint was in each bale. The curves from the models were plotted to compare them with the observed data and to verify that the model fit the data. The time in days for a bale to change half the potential weight change was calculated based on the parameter b for different bagging types and tabulated. Several models representing the range of the parameter b were plotted together so that they could be compared visually.

**High permeability bale bags**

The data with bales covered with high permeability bagging were examined after 69 days of storage and were observed to have changed substantially in weight. After fitting the data with models based on equation 4 the results were judged to be adequate and the bales were removed from storage and sold.

**Low permeability bale bags**

The data with bales covered with low permeability bagging were examined after 69 days of storage and were observed to not have changed substantially. They were held until 155 days had passed when data collection was ended. The data were modeled with one b parameter for
each bagging material. Additionally models were developed with a common proportion of weight change from beginning to equilibrium, not achieved during the test but estimated from the statistical regression, for all bales.

**Bags with punched holes**

The data were examined and judged to have changed sufficiently after 63 days of conditioning. Models were developed which used a b value based on the number of holes per unit area and with one proportional weight change for all bales in this portion of the study. A second model incorporating the percentage of hole area per surface area of the bagging was also fit to the data.

**Results and Discussion**

**High permeability bale bags**

The weight data for the six bales were modeled with three parameters per bale for a total of 18 parameters resulting in an error mean square (EMS) of 0.0243 and root mean square error (RMSE) of 0.16 kg. Then the model was simplified with b values the same for each set of two bales with the same bagging which included 15 parameters for the six bales resulting in an EMS=0.0238. The b values were not significantly different so one value was used for all six bales resulting in the best fit of the three models used with RMSE=0.15 kg. The b value for these bales was 0.0345 with an estimated standard error of 0.001. Figure 2 shows the individual bale weight data from this portion of the study and the single model for all six bales.
Figure 2. Weight ratio for all six bales with either no bagging or highly permeable bagging, which did not have statistically different weight changes over time, points, and model which fit all data, line. For the most part the observations were so close together that the individual points cannot easily be distinguished.

**Low permeability bale bags**

The bale weight data for the three types of bagging materials were modeled with 18 parameters based on equation 4, then with a reduced number of parameters with one $b$ value for each bagging type. Finally a model was developed with one $b$ parameter for each bagging type, one parameter for the percentage weight change for all of the bales, and one parameter representing the final weight of each bale, for a total of 10 parameters. The last model fit the data best with a RMSE=0.12 kg. Figure 3 shows the bale weight data, points, and the models for the bales, lines. The two bales with LLDPE bagging with no holes can be observed to be particularly slow to change weight.

![Graph showing weight over time of six cotton bales in low permeability bagging, points, and models determined by regression, lines, which fit the weight data.](image)

Figure 3. Weight over time of six cotton bales in low permeability bagging, points, and models determined by regression, lines, which fit the weight data.

**Bags with punched holes**

Six bales were prepared with six levels of holes punched in them. The model which was used had one final bale weight for each bale and one factor representing the projected total weight
change proportional to the final projected bale weight. In addition one time rate of change coefficient was used which was multiplied by the number of holes per unit area by the model, for 8 parameters, equation 5.

\[ W(t) = WFn \times (dWf \times \exp(-b \times N \times t) + 1) \]  

(5)

where

- \( W(t) \) = the bale weight at time=t, kg,
- \( WFn \) = the final bale weight for bale n, kg,
- \( dWf \) = the proportion of the total bale weight change to the final bale weight,
- \( b \) = the time rate of change coefficient, per day,
- \( N \) = the number of holes in the bagging per unit area, and
- \( t \) = time, days.

There were a total of 10 weight observations for each of six bales over 63 days of conditioning. Nonlinear regression was used to choose \( WFn \), \( dWf \), and \( b \) for equation 5. The F value of the model was 1.16E7, obviously highly significant, and the resulting RMSE was 0.19 kg, considered to be reasonable for this data. Figure 4 shows the model with the six different number of holes per unit area plus the model for the LLDPE bag with no holes from the previous regression.
Next a model with one parameter value for the rate of bale weight change per percent of bagging open area in place of the coefficient per hole was included for 8 parameters in the model. This model should fit the data the same as the previously described model, but be more useful in bagging design. The unit area was 3456 cm² and the holes had an area of 0.95 cm² or 0.0275% of the total unit area per hole. The resulting EMS was 0.0371 with this data set for a RMSE, sometimes called standard error, of 0.19 kg (0.4 lb). The resulting rate of weight change was estimated to be 0.148 per day percent hole area with a standard error of 0.03. The bags with two holes per unit area had a total open space of about 0.05% of the bag surface and a half time to equilibrium of 85 days, while the bags with three holes per unit area had an overall open space of about 0.08% of the bag surface and a half time to equilibrium of 58 days. These hole arrangements may provide an acceptable level of permeability to moisture, although not nearly as great as for cotton or burlap bags.

**Overall data**

Table 3 lists the b values for the data described in this study and the half time to weight equilibrium for bales in the bagging tested. These data demonstrate the tremendous difference in weight change rate as measured by half time to equilibrium for bales in the different types of
bagging included in this study, from 20 days for the bare bales and bales with cotton or burlap bagging, to 85 days with LLDPE bags with substantial holes cut in them, to 124 for fully coated spiral sewn WPP bags, to 1136 days for LLDPE bags with no holes. These data also support the concept of increasing the bale weight change rate by making holes in the bagging.

Table 3. Cotton bale bagging ID, weight change coefficient from model of data using equation 4, and half time to equilibrium for increasing bale weights.

<table>
<thead>
<tr>
<th>Bale bagging</th>
<th>Coefficient b (days⁻¹)</th>
<th>Half time to equilibrium (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare, cotton, burlap</td>
<td>0.0347</td>
<td>20</td>
</tr>
<tr>
<td>WPP, spiral sewn</td>
<td>0.00559</td>
<td>124</td>
</tr>
<tr>
<td>WPP, seamless, fully coated</td>
<td>0.00204</td>
<td>340</td>
</tr>
<tr>
<td>LLDPE, no holes</td>
<td>0.00061</td>
<td>1136</td>
</tr>
<tr>
<td>LLDPE, holes as distributed</td>
<td>0.00816</td>
<td>85</td>
</tr>
</tbody>
</table>

Summary

A total of 18 Universal Density cotton bales were placed in a total of 12 different bagging materials, including no bagging. The bales were stored in a chamber with relatively constant and high humidity with the bale weights being measured periodically. The weight data for the first few days was not included in the analysis and the bale weight data did not continue through the time to equilibrium. A single term exponential decay model was fit to the data which fit well with a different coefficient for initial bale weight, total bale weight change for each bale; and a different rate of bale weight change coefficient for each bagging material. The bale weight data for two bales with the same bagging material agreed well.

The half time to bale weight change equilibrium was calculated for bales in each bagging type and varied from 20 to 1136 days. The analysis of bale weight change data which produces a rate of bale weight change will allow the estimation of the half time to bale weight equilibrium without actually storing the bales until they approach equilibrium. The half time is a simple number which allows ranking bale bagging for those concerned with the rate of change of bale weight during storage. The number communicates in a simple way a rather complicated process which will allow better communication among those concerned with cotton bale weight changes during storage.

References