COB-2023-1452

Experimental estimation of the moisture content of cotton bales through required hydraulic force

André A. Fernandes
andre_araujof@usp.br
Gabriel Alberto Bermudez Arias
gabrielbermudez@usp.br
André Vecchione
andrevecchione@usp.br
Thiago Boaventura
tboaventura@usp.br

University of São Paulo - Av. Trab. São Carlense, 400 - Parque Arnold Schimidt, São Carlos - SP, 13566-590

Abstract. Measurement and control of the moisture content (MC) of cotton bales is a primary issue in cotton ginning. Low MC reduces profitability due to lower fiber quality and production, weightwise. If the MC is too high, it is harder to clean and separate the lint from the seed, and the bales degrade in storage. The dielectric properties of cotton are greatly affected by water, and most commercial MC sensors are based on this effect. Microwave sensors and impedance sensors are common off-the-shelf solutions with significant drawbacks. Microwave sensors are expensive and stationary, while impedance sensors require significant labor and time. A less common way to measure the MC is through the mechanical effort required to press the cotton lint into a bale. There is a direct relationship between the force exerted by the hydraulic press and the overall MC of the bale, for bales of the same density. This article investigates this relationship by measuring the maximum hydraulic pressure when baling and the real MC through oven drying. To generate the required data, an automated hydraulic press was used to manufacture reduced-scale cotton bales following commercial standards. The Least Squares Method was used to fit a curve into the data following a model already existent.

Keywords: Moisture Content, Cotton Bale, Cotton ginnning, Hydraulic press.

1. INTRODUCTION

Cotton ginning is the mechanical process of separating the cotton fiber from the seed. The term is often used to describe the entire process of taking seed cotton and producing cotton bales. The ginning process has three main steps: drying and pre-cleaning, ginning, and fiber cleaning and balling. Figure 1 shows these three types of cotton. Harvested cotton is called seed cotton and the fiber is called lint cotton.

The quality of the fiber produced is highly dependent on the efficiency of each step and the efficiency of each step is strongly influenced by the moisture content (MC) of the cotton (Costa *et al.* (2000)). If the MC is too low, the fiber breaks during ginning, there is a higher chance of igniting due to sparks generated by static electricity, higher balling press wear, and loss of profit due to lower production weightwise. If the MC is too high, the bales deteriorate when stored, cleaning is harder, and the machines can get clogged. It is common practice to measure the MC of the bale before storing it.

MC is often measured using the dielectric properties of cotton (Pelletier and Byler (2020)), as they are directly dependent on the amount of water in the fiber. Commercial solutions include handheld contact sensors and stationary noncontact sensors (Rodgers *et al.* (2014)). Contact sensors use probes to measure the capacitance or resistance of a small region of the material. These measurements require significant labor and must be performed several times to estimate the MC of the whole bale. Noncontact sensors propagate microwaves through the material and measure changes in amplitude and phase, keeping variables such as distance and alignment constant. Microwave sensors are often positioned where they can sweep the bale. Typically, they are mounted on the sides of the conveyor belt that transports the bale to be stored.

Bales are formed by compacting a large volume of lint cotton using a hydraulic press. The volume of lint cotton that is baled at a time is determined by its weight. Two bales with the same weight but different MCs have different amounts of lint cotton, due to water weight. The bale with less lint cotton is easier to press, resulting in lower pressure in the hydraulic actuator compared to a bale with the same weight and lower MC. Hence, it becomes possible to estimate the bale MC through the required hydraulic force.

The work of Anthony (1994) proposes that the MC of compressible materials, including cotton, can be estimated during the compression cycle using an equation that relates the MC with the force applied and the density of the cotton bale at the end of the press process. The hydraulic force required to press a cotton bale at a specified density and MC can

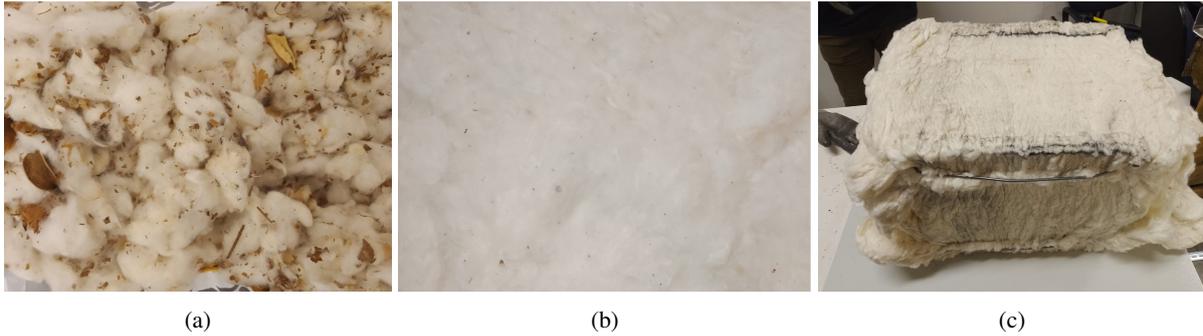|		
(a)	(b)	(c)

Figure 1: Cotton at different stages of the ginning process: a) Seed cotton, as harvested on the field; b) Lint cotton, the cotton fiber after being cleaned; c) Cotton bale, made from compressed lint cotton.

be predicted by Eq. (1). The same equation can then be used to predict the bale MC by keeping track of the hydraulic force applied. In Anthony (1998), this equation was applied to 27 bales and achieved a $\pm$ *0.5%* precision when compared to the oven-drying method. On the Eq. (1), M_c is the moisture (percentage), F (kN) is the applied force at the end of the compression cycle and ρ (kg/m^3) is the density of the bale at the end of the compression.

$$M_c = 47,09 - 33,19 \, \log F + 81,21 \, \log \rho \tag{1}$$

In this work, the relationship between bale MC, density, and required hydraulic force is identified through experimental data. Scaled-down bales with different MCs and densities were produced to generate a data set. The Least Squares Method is used to fit a line for the collected data, following the same model proposed by Anthony (1994). Section 2. details the experiment and the hardware employed. Section 3. details the data collected and the proposed equation.

2. EXPERIMENTAL PROCEDURE

The experimental procedure consists of the following steps:

- MC conditioning of cotton samples
- Storage of samples in hermetic bags
- Weighing of the samples
- Manual pre-compression of the samples into the container
- Compression to the specified dimension and data acquisition
- Breaking up of the bale into baskets
- Oven-drying process

The scaled-down cotton bales produced have *300×300×300* mm and weigh roughly *10* kg. Steam was used to change the MC of the cotton samples before the pressing stage. The typical MC range of commercial cotton bales is between 5 and 14% (Belot and Vilela (2020)). The samples are stored in hermetic bags for 24 hours to homogenize the MC distribution. The samples are compressed by hand into a container and then pressed by the hydraulic actuator. The samples are then placed in baskets and hung on a structure inside a drying oven. This structure is attached to a load cell outside the oven. As the water evaporates, the samples become lighter, to the point where there is no significant weight change over a considerable time period. The standard value is a variation less than 0.05% of the initial weight after 15 minutes. Figure 2 shows this weight variation over time for a cotton sample. The weight variation can be compared to the initial or the final weight, known as wet-basis and dry-basis, respectively. This oven-drying method follows the ASTM D2495-07 standard (Subcommittee (2001)).

2.1 Hardware setup

The hydraulic system is comprised of a hydraulic actuator, Hydraulic Power Unit (HPU), directional valve, pressure transducers, and a Programmable Logic Controller (PLC). The hydraulic components can be seen in Figure 3. The hydraulic actuator can produce *533* kN at *200* bar. The hydraulic power unit used has an *80* L reservoir and fixed flow of *3×10^{-4}* m^3/s or *18* L/min. The directional valve has 4 ways and 3 positions. Two RS 797-4986 pressure transducers were placed along the A and B pressure lines at the manifold. Valve control and data acquisition are performed by the Siemens Simatic 1214C S7-1200 DC/DC/DC PLC.

The container used to make the bales is shown in Fig. 4. It was built with 1/4" steel plates and aluminum profiles. Cotton is pilled on top of the wires and after the bale is pressed, one end of the wire is pushed back into the container through the gaps, guided by the canal on the rod attachment, and tied at the front of the container. The walls of the
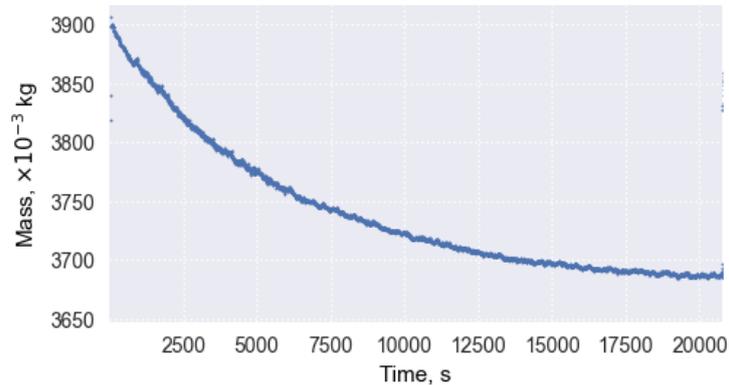
Figure 2: Weight variation of cotton samples throughout the oven drying process.

Figure 3: The hydraulic system used in the experiments (a) HPU and hydraulic actuator; (b) Directional valve; (c) Pressure transducer mounted on the manifold.

container can then be easily removed to extract the bale. The plates and aluminum profiles are assembled with bolts and nuts.

Due to the size of the container and the stroke length of the hydraulic actuator, it is not possible to compress the bale in a single stage. It is required 2 to 3 precompressions, where the actuator will make low-density bales until all the samples have been used. Although this is how commercial bales are produced, compressing precompressed lint cotton lowers the maximum force required to press the bale and makes it hard to compare bale production. Therefore, the produced bales were precompressed only by hand, without the hydraulic actuator.

The drying oven used is the MARCONI MA35. Cotton samples are placed inside baskets made of galvanized wire. These baskets are approximately 180×800 cm. The steam required to increase the MC of the samples is generated by a steam cleaner and is applied directly to the samples from a short distance. These baskets are hung on hooks on the metal

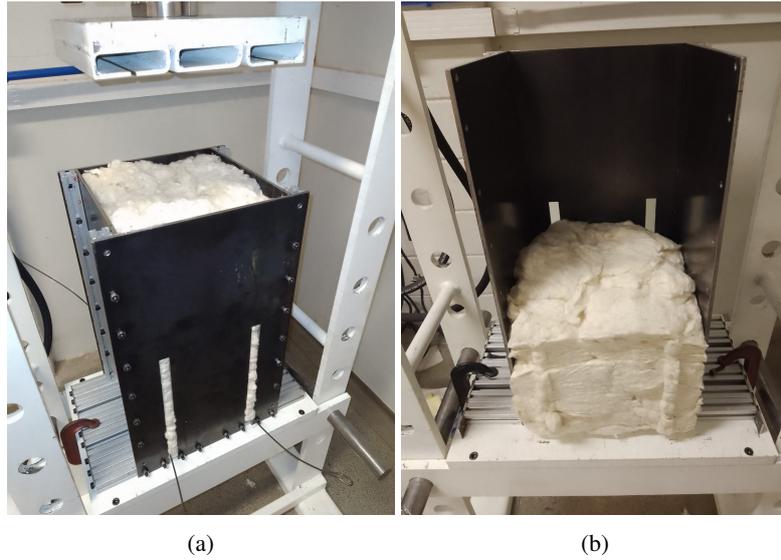(a)   (b)

Figure 4: Container used to make cotton bales: a) Before pressing; b) One side is open to extract the bale.

structure, which itself hangs from a load cell placed on top of the oven. The load cell and the metal structure are attached by a threaded rod that goes through the roof of the oven through a ventilation opening. The other end of the load cell is screwed to a U-shaped support. The whole assembly can be seen in Fig.5. The measurement system consists of the SMT1-250 load cell, with an HX711 module for signal conditioning and conversion and an Arduino for data acquisition.

Figure 5: The MARCONI MA35 drying oven with the system to measure the cotton sample's weight while drying.

3. Results and discussion

The Python library NumPy was used to fit data points with the least squares method. These data points are from 20 bales with different MC. The model considered is the same as that used by Anthony (1994) and can be rewritten as in Eq. (2). Hence, the data points gathered by the experiments are used to find the coefficients of Eq. (2).

$$M_c = \beta_1 + \beta_2 \ \log F + \beta_3 \ \log \rho \qquad (2)$$

Equation (3) was obtained with the *numpy.linalg.lstsq* function. MC is given in percent, force F in kN, and density ρ in kg/m^3. Figure 6 shows the line obtained by Eq. (3) showing what are the expected values of MC and Force for 5 different bale densities. The data used to feed the linear regression algorithm and obtain the Eq. (3) can be found in Tab. 1. The coefficient of determination (R^2), the mean square error (*MSE*) and the mean absolut error (*MAE*) were also calculated, giving the following results: $R^2 = 0,837$; *MSE = 0,629*; *MAE = 0,665*.

$$M_c = -17,36 - 7,30 \ \log F + 13,78 \ \log \rho \qquad (3)$$

Figure 7 presents the data points gathered by the experiments together with the curve given by the Eq. (3) that fits the points. The curve represents a plane when force F and density ρ are plotted on logarithmic scales.
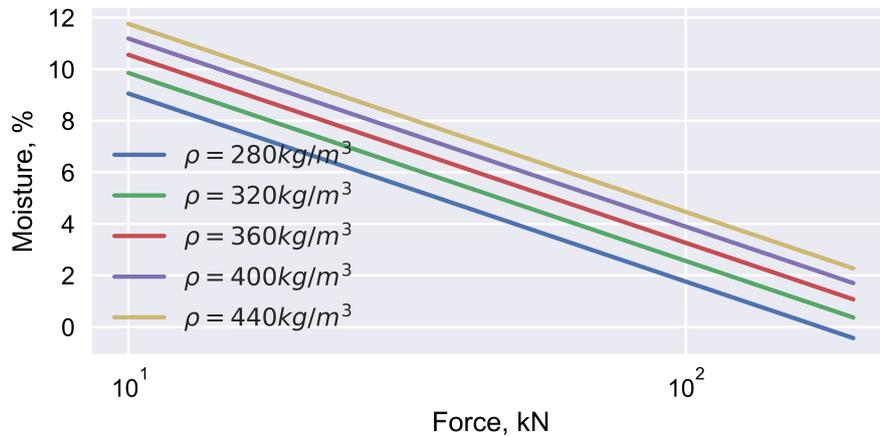
Figure 6: Implementation of the equation obtained to predict the MC of a cotton bale based on the force applied to obtain a specific density of the bale.
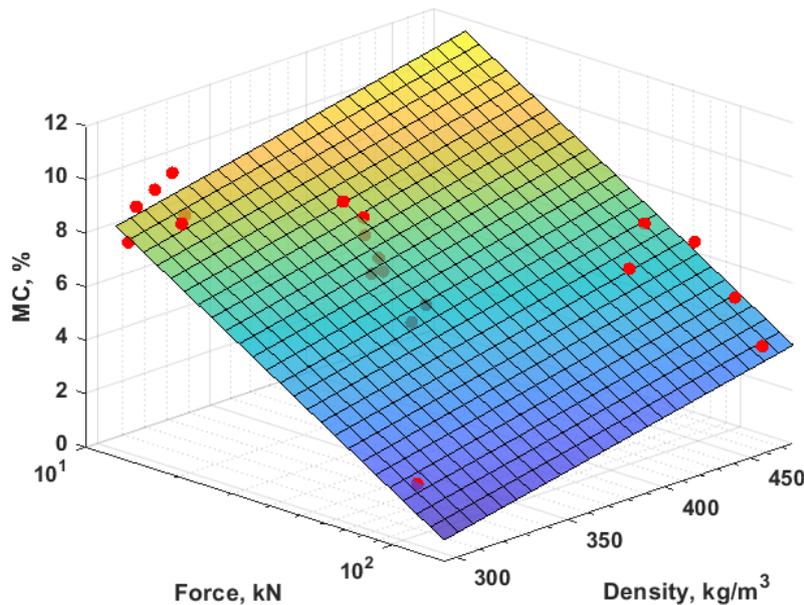

Figure 7: Scatter plot of the data collected through the experiments and the fitting plane following the model proposed by Anthony. (Both force and density are plotted on logarithmic scale).

Pressure data from the compression cycle were also measured and plotted, as shown in Fig. 8. The values of the pressure at the end of the cycle (near 110 s) are the ones used to calculate the force at the end of the cycle and therefore is the force that is substituted into Eq. (3).

4. Conclusion

A hydraulic press was designed and built for the purpose of manufacturing cotton bales and conducting research on the relationship between the applied force and the moisture content (MC) of the cotton bale. A total of 20 cotton bales were produced, and data on pressure, MC, and density were collected. An equation relating MC, bale density, and applied force was obtained. Both density and force are collected at the end of the cycle.

The equation obtained does not correspond to the original equation proposed by Anthony (1994) (the coefficients obtained for each term differ from the original equation). This must happen because the range of each parameter used in each work is different: the range of forces differs and each hydraulic press has different area. Hence, the Eq. (3) obtained in this work is universal for a hydraulic press but not for all.

Table 1: Measurements taken from the cotton bale manufacturing process. The pressures and the density are measured at the end of the cycle. The MC is obtained from the oven method.

MC, %	p_1, MPa	p_2, MPa	ρ, kg/m^3
5.12	43.570	12.948	468.15
6.17	30.237	10.489	436.58
6.83	22.823	7.397	467.32
4.05	54.938	10.183	457.02
2.07	45.985	17.282	303.50
9.28	4.938	0.922	300.0
8.76	6.168	1.230	307.24
8.17	5.553	1.537	294.77
9.62	5.553	1.845	308.8
7.93	10.183	3.391	368.38
10.15	5.245	1.230	314.22
6.37	31.787	12.344	477.08
8.72	9.568	2.776	359.59
5.30	14.813	4.006	370.78
6.32	13.266	5.245	364.99
6.62	13.610	4.770	354.47
4.92	15.120	4.006	361.76
7.35	11.105	4.314	367.20
6.55	9.568	1.537	369.60
8.17	4.938	1.230	324.03
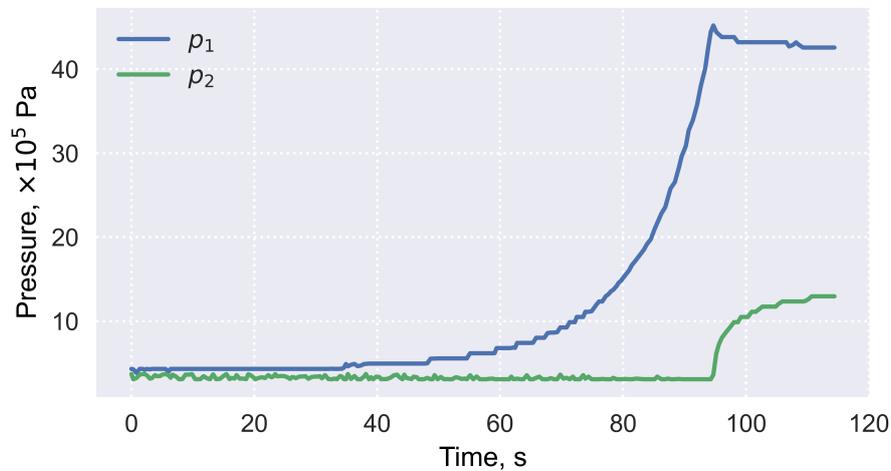
Figure 8: Pressure during the compression proceeding of the lint cotton.

5. ACKNOWLEDGEMENTS

6. REFERENCES

Anthony, W.S., 1994. *Cotton ginners handbook*. 503. Department of Agriculture Agricultural Research Service.

Anthony, W., 1998. "Development of a method to estimate the moisture content of cotton bales". *National Cotton Council Beltwide Cotton Conference*.

Belot, J. and Vilela, P., 2020. "Manual de boas práticas de manejo do algodoeiro em mato grosso". *Cuiabá: IMAmt*.

Costa, J., Almeida, F., Santana, J., Costa, I., Wanderley, M. and Santana, J., 2000. "Técnicas de colheita, processamento e armazenamento do algodão". *Embrapa*.

Pelletier, M.G. and Byler, R.K., 2020. "COTTON GINNERS HANDBOOK: Moisture measurement". *Journal of Cotton*

Science, Vol. 24, No. 3, pp. 121–130. doi:10.56454/tigg3482. URL `https://doi.org/10.56454/tigg3482`.

Rodgers, J., Fortier, C., Kang, S.Y., Montalvo, J. and Hoven, T.V., 2014. "Cotton fiber moisture measurements: A comparative evaluation". *AATCC Journal of Research*, Vol. 1, No. 5, pp. 24–33. doi:10.14504/ajr.1.5.4. URL `https://doi.org/10.14504/ajr.1.5.4`.

Subcommittee, A., 2001. "Standard test method for moisture in cotton by oven-drying". ASTM.

7. RESPONSIBILITY NOTICE

The authors are solely responsible for the printed material included in this paper.