VOL. 4, NO. 5, JULY 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

COMPRESSIBILITY OF SINGLE UN-RENDERED RICE STRAW BALES: CHARACTERISTICS OF BALES USED FOR BUILDING

Gihan L. Garas, Mostafa E. Allam, Hala M. El Kady and Ayman H. El Alfy
National Research Centre, Civil Engineering Department, Dokki, El Tahrir St., Cairo, Egypt
E-Mail: gihangaras@yahoo.com

ABSTRACT

Straw bale construction has recently gained more confidence to be used as structural elements. A number of laboratory tests worldwide, show this system to be capable of supporting substantial service loads in case of proper baling, stacking, and plastering. In Egypt, growing attention is focused on examining this new trend of construction in order to solve the environmental pollution caused by burning millions of tons of straw every year. Two types of mobile straw baling mechanical powered press machines are commonly used in Egypt, private local small sized iron baling machines and Cicoria straw baling machines. These two baling systems have major differences in their end product physical properties, baling, and mainly their compressing techniques. Rare information is available about the mechanical characteristics of local bales. This paper is part of a pioneer national project aiming to use rice straw bales in building. The research aims to identify the specifications and characteristics of locally produced rice straw bales used for building. The bales are compressed under various compressibility conditions to identify the settlement that is expected to happen in most of the types of bales available in the market. Experimental studies are carried out on the effect of compressibility and baling on the quality of single un-rendered straw bales in general, and particularly it's displacement under vertical load. These experiments are conducted on single un-rendered bales from different sources, by applying incremental vertical load, reaching 50 tons. Results of corresponding displacements of different types of bales from different sources are recorded and compared together. It was found that bales compressed by private local small sized iron factories show the least displacement values that did not exceed 3.0cm when subject to a maximum of 50 ton vertical load. Finally, recommendations are given for safe application of such bales in construction.

Keywords: rice straw, construction, baling machines, compression, building codes.

1. INTRODUCTION

Straw bales consist of cheap abundant cellulose fibers packaged into conveniently, sized rigid bundles that are suitable for building. Any conventional building method, if used to build walls of the same thickness as a bale wall, would provide similar levels of performance, but at a much greater financial and environmental cost. Bales work cheaply and sustainably.

The most common types of straw are wheat, oats, barely and rice. All of these are commercially farmed in most parts of the world. It is possible to bale and build with almost any fibrous plant stems. These types of straw are considered a waste by-product of grain production. Most probably excess straw is burned in the field, contributing seriously to air pollution. [Magwood *et al.*, 2005]

1.1 Constituents of rice straw

Rice straw is composed- by volume- of the following constituents in descending order:

- Cellulose (about 40% of volume): very long cellulose microfibers consisting of crystalline regions that provide the tensile strength and structure of the plant.
- Hemi-cellulose (about 25% of volume): Shorter and less crystalline molecules that act as a structural adhesive to bind the long cellulose fibers.
- Ash and other minor constituents mainly silicon dioxide (about 20% of volume). The more of this silica ash present in the plant, the better the resistance to fire and decay.
- Lignin (about 15% of volume): It is the glue that binds the whole thing together, akin to the way concrete surrounds rebar to create a composite structure [King, 2006].

1.2 Quality of straw affecting the bales

Different baling machines produce bales of differing quality. Even bale quality from the same machine can vary, depending on the sharpness of the cutting blades, and the adjustments made for the tightness of the strings. The best bales contain high percentages of long, unbroken straw.

Magwood Chris *et al*, 2005, argued that there are three basic concerns that mainly affect the bales quality: tightness, dryness and size.

Tightness: Bales are tied with polypropylene string, sisal twine, or metal wire. Farmers can adjust the baling machine to vary the tightness. Tight bales use less twine or wire to bale the straw but the end bales are heavier and harder to handle. Methods for assessing tightness vary from low tech to the scientific. The California Straw Codes specify that bales should have a minimum calculated dry density of 7.0 pounds per cubic feet (112 kg/m^3).

Dryness: Like any organic material, straw will decompose. If the right conditions of moisture and temperature exist, then the builder would remove one of the essential factors of decomposition. Moisture content of 20% is considered the safe maximum for a building bale.

Size: This factor is the least important for building bales. As long as the bales are of consistent height and width, their exact dimensions are not so important [Magwood *et al*., 2005].

Bruce King, 2006, agreed on two particular other qualities that affect the bales. These are:

Type of grain: There seems little difference among the qualities of different cereal grains such as wheat, barely and rye. However, two factors make rice straw bales better than all others which are the high silica content that makes the straw more resistant to decay and the slightly barbed surface of the straw that makes the strands tend to grab each other resulting in bales that remain coherent when cut or untied.

Fertilizers: Many people argued for the use of organically grown straw for building bales, on the logic that agricultural pesticides shouldn't, for health reasons, be buried within the structure of a building. However, evaluation of pesticides and their importance must be left to each individual case, considering both the batch of bales and the sensitivity of builders and occupants. Bruce also reported five qualities that determine the characteristics of acceptable bales for building which are moisture content, density, history of bales, fiber length and being precise in using straw not hay [King, 2006].

2. RESEARCH SIGNIFICANCE

Bales of various types of straw, including, wheat, rice, rye, barley, oats and similar plants, may be used in building if they meet the minimum requirements for density, shape, moisture content, and ties prescribed by the various applied worldwide codes. According to the California baling codes and the Texas City codes, bales must be rectangular in shape and of consistent height and width to ensure even distribution of loads within wall systems. Also, bales must be bound with ties of either polypropylene string or baling wire.

The codes insist that the moisture content of bales may not exceed 20 percent of the total weight of the bale at the time interior and exterior finish materials are applied. Moisture content may be measured in the field using a suitable moisture meter, designed for use with baled straw or hay, and equipped with a probe of sufficient length to reach the center of the bale. This instrument may be used to determine the average moisture content of 5 bales randomly selected from the bales to be used in building. Bales must have a minimum calculated dry density of 7.0 pounds per cubic foot (112 kg/m^3). The calculated dry density is determined after reducing the actual bale weight by the weight of the moisture content. The calculated dry density is determined by dividing the calculated dry weight of the bale by the volume of the bale [Austin and California codes].

3. PROBLEM STATEMENTS

Approximately 4 million tons of rice straw are produced in Egypt annually and are disposed of most of it by burning causing high degrees of environmental pollution known as the Black Cloud [Garas *et al*., 2008].

An amount of 1-1.5 % of the produced rice straw is being baled at the end of the harvest season in different manners aiming to remove the straw -which is considered an agricultural waste residue- as soon as possible from the land .Some of these bales are used instantly for various reasons such as feeding cattle, producing biogas, and in paper factories. The rest is stored in bales to be used later during the whole year as animals bedding and in cultivating some secondary agricultural products such as mushroom [Tamer, 2006].

Despite all the legislations and penalties undertaken by the government to restrict the burning of rice straw, the major amount is burned by the small farmers who cannot afford the price of baling thus getting rid of this residue as soon as possible.

The project adopted by the National research Center in Egypt, is considered a pioneer complete project that aims to research on the different aspects of using great amounts of the rice straw produced each season in building economic houses instead of burning it.

4. BALING SYSTEMS IN EGYPT

The main purpose of baling systems in general is to save valuable storage space. This can be achieved by compacting loose materials of low density to a higher density material in uniform shapes using different types of press machines. Loose straw is produced every year at the end of the rice plantation season. It is usually collected at big space in its loose form on the farmers' agricultural land. For next plantation cycle to begin the farmer has to get rid of the collected straw either by baling it to fit in smaller storage spaces to use it as an in-expensive feeding for his animals or to burn it and cause environmental pollution. Straw is either baled in the row straw form or in the chipped form.

4.1 Commonly used press machines

Two types of mobile straw baling mechanical powered press machines are commonly used in Egypt.

The first type (Figures 1 and 2) is produced in mass production by the Arab Organization for Industries-Kader Factory for Developed Industries named (Cicoria), it is generally used by the governmental Straw Collecting Centers that provides straw baling services for the farmers. This kind of press is used only for rice straw at its hay condition.

The second type (Figures 3 to 5) of straw baling presses is produced by private local small sized iron factories. It is custom made to fit the requirements of straw bale size of the client and it can be either used to press rice straw at its hay estate or in its chipped estate.

A third type (Figures-6) of hydraulic bailing press that is mainly used for baling scrap materials can be applied for rice straw baling. The press uses electrical powered hydraulic piston with gadget to control pressing pressure values. The press is custom made to fit the client requirements through the required bale size and the desired pressing pressure.

All straw bales produced from previously mentioned presses can be double tied using either polypropylene ropes or metal string.

4.2 Comparison between the technical specifications of the previously mentioned straw bale presses

Table-1 presents a comparison between the two commonly used press machines in Egypt. The third type which is recommended to be used in future for producing consistent bales for building is presented.

Table-1. The technical specifications of straw bale presses.

Model	Units	TYPE 1 A.O.I Kader 2545	TYPE 2 Private Local Manufactured	KEFAC Hydraulic KBVN-05
Compressing Force	Tons	NA	NA	5
Tying Slots	Number	2	Varies	3
Electric Motor	HP			3
Mechanical Motor	HP	30	30	
No of strokes / Min		88 Dist 75 Cm	88	
Cycle Time Dry	Seconds			30
Chamber Size(L x W x H)	CM	Var. x 37 x 47	50-150 x 55 x 45	60 x 80 x 120
Bale Size (L x W x H)	CM	130 x 40 x 40	150	60 x 80 x Var.
Productivity	Bale / Hr	150-200	70-100	50-70
Bale Weight	KG	20-50	40-50	30-40
Press Overall Dimensions	CM	L 450 W 240 H 160	L 600 W 100 H 160	60 x 100 x 200

First type of straw bale press

The press type (Figure-1) is an Italian Egyptian join venture product. When used on the mobile condition the press pulled by agricultural tractor -which supplies its mechanical power- it collects the straw from the field and compresses it at one time. When the press is used on the steady condition it uses the manual feeding and tractor mechanical power.

(Figure-1).

The degree of compressibility at the straw bale horizontal sides is controlled by two adjustable vertical iron fins. The compressibility of straw bale vertical sides is controlled by one adjustable horizontal iron fin. The straw bale length is an adjustable factor-the press operator can stop pressing the bale and tie it at any time when the bale reaches its desired length. (Figure-2).

(Figure-2).

Second type of straw bale press

This type of straw bale press (Figure-3) is manufactured by small private Egyptian iron factories. Although this press is mobile, it only operates on the steady condition at the straw collection pints using manual feeding and tractor's mechanical power.

VOL. 4, NO. 5, JULY 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

(Figure-3).

Since the press is custom made the desired bale dimensions can be achieved, and it can be used to press straw on all its states (Figure-4).

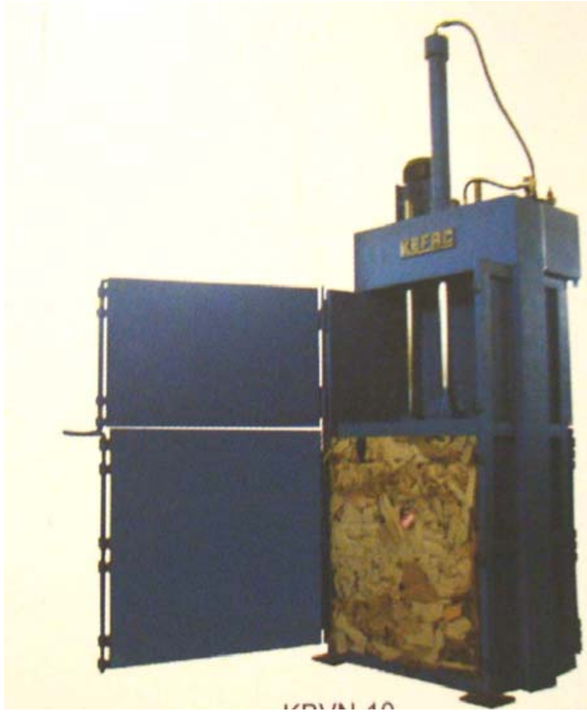
(Figure-4).

Metal string or plastic ropes can be used to tie the Straw bales.

(Figure-5).

Hydraulic type of straw bale press

Although this type of press is manufactured for scrap metal bailing yet it can be used for rice straw bailing. It is available in vertical shape as shown in (Figure-6).



(Figure-6).

5. MATERIALS AND METHODS

5.1 Specimens description

The specimens used in this research are rice straw bales of nearly similar dimensions around 1.0m length, 0.55 m width and 0.5 m height. The specimens were taken randomly from different sources. This meant different baling machines were used in baling the straw as well as using different tying strings and different degrees of tightness. Also, the weight of the bales varied from one source to another resulting in various densities. All specimens were un-rendered during the experiment and were laid flat, but were tied with two polypropylene strings.

5.2 Compression test setup and procedure

5.2.1 Instrumentation and experimental setup

In order to perform compressibility tests on individual bales, a 100 ton hydraulic piston, equipped with two levels of speed control (fast and slow) is used. The piston is mounted on a steel frame with clear height of two meters, to provide the facility of testing full scale walls in the future. To insure uniformity of load distribution on the bales, a wooden frame is manufactured with a rigid round top (Figure-7).

Displacements are measured using 2 Linear dynamic transducers (LVDTs) connected to a data acquisition system.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Figure-7. Hydraulic piston for compressing the bales and a wooden support for uniform load distribution on bales.

5.2.2 Specimen specifications

Three groups of locally available rice straw bales were tested. These groups present different sources and methods of pre-compression applied in Egypt. Prior to compressibility test, the following measurements were obtained for each bale: dimensions, weight, and moisture content.

Group 1:

The first group includes samples produced by straw baling mechanical powered press machines type 1 (Cicoria). Table-2 presents the physical specifications of this group of bales.

Group 2:

The samples of the second group are produced by private local pressing machines type 2 used by individual farmers. Specifications of samples group 2 are listed in Table-3. Some irregularities in bale's dimensions were visually noticed in the samples of this group prior to commencing the experiment.

Group 3:

The third group presents samples produced also by private local pressing machines type 2 used by individual farmers but with better and enhanced compressibility. Table-4 presents specifications of samples group 3.

Table-2. The physical specifications of straw bales group1.

Sample	**Dimension** (m)			**volume**	**weight**	**Density**	**Moisture content**
No.	Length	width	height	(m^3)	(kg)	(kg/m^3)	(%)
1	0.97	0.5	0.32	0.155	13	84	19
2	0.84	0.51	0.38	0.163	13	79	19
3	0.97	0.48	0.36	0.168	14.5	86	19
4	0.92	0.5	0.35	0.161	14.5	90	19

Table-3. The physical specifications of straw bales group2.

Sample	**Dimension** (m)			**volume**	**weight**	**Density**	**Moisture content**
No.	Length	width	height	(m^3)	(kg)	(kg/m^3)	(%)
1	1.10	0.45	0.48-0.51	0.2525	31	122.8	19.1
2	1.13	0.47	0.47-0.50	0.2656	34.5	129.8	19.1

Table-4. The physical specifications of straw bales group3.

Sample	**Dimension** (m)			**volume**	**weight**	**Density**	**Moisture content**
No.	Length	width	height	(m^3)	(kg)	(kg/m^3)	(%)
1	1.01	0.52	0.51	0.268	37	138	16.9
2	0.98	0.50	0.50	0.245	36.5	149	16.9
3	1.00	0.55	0.49	0.269	39	145	16.9
4	1.03	0.53	0.51	0.278	41	147	16.9

6. RESULTS

Group 1 consisted of 4 bales from one source. The bales were compressed using the Cicoria baling machine type 1 and tied with polypropylene tying strings.

Visual inspection of samples 1 and 2 showed that they were inconsistent in dimensions and loose by the time

ARPN Journal of Engineering and Applied Sciences

of applying the test. Figure-8 presents the recorded results of compressing only the 2 bales (samples 3, 4) of the highest density of group1. By visual inspection those2 bales showed consistency in dimensions and better tightness conditions. The maximum vertical compressibility of sample 3 was 25 cm under a load level 50 ton while sample 4 showed better settlement of 17 cm upon exposure to the same load level. The samples were exposed to one cycle of loading due to the great displacement shown.

Group 2 included 2 bales compressed by the local pressing machine of a farmer produced by a private small sized iron factory (type2) tied with sisal twine polypropylene string. The samples of this group were exposed to two compressing cycles of loading. In each cycle the piston was removed completely to allow the bales to recover its displacement. The first sample was presented in Figure-9 which shows the load-displacement curves for this bale. It is noticed that the maximum compressibility recorded is 20 cm after cycle 1 of loading then decreased to 8 cm in the second cycle when loading up to 50 ton. The second sample presented in Figure-10 showed initial vertical displacement of 16 cm upon loading 50 tons in the 1st cycle, and decreased to reach 11cm in the 2nd cycle.

Group 3 consisted of 4 bales taken randomly of a group of 500 bales. Those were compressed using the compressing machine type 2 of a private small sized iron factory. According to the visual inspection, the samples were highly consistent in dimensions and tied firmly with sisal twine polypropylene string at distances around 1/3 the bales' width. Figure-11 shows much better displacement results of the third group which encouraged the researchers to eliminate the re-cycling process to one cycle only. Maximum vertical compressibility did not exceed 3.0 cm when bales were loaded to 50 ton.

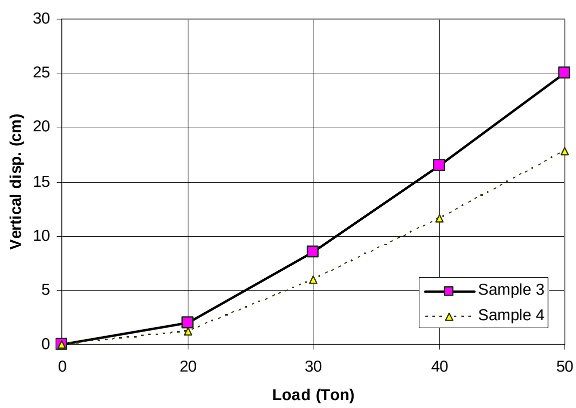


Figure-8. Vertical loading of un-rendered bales group1.

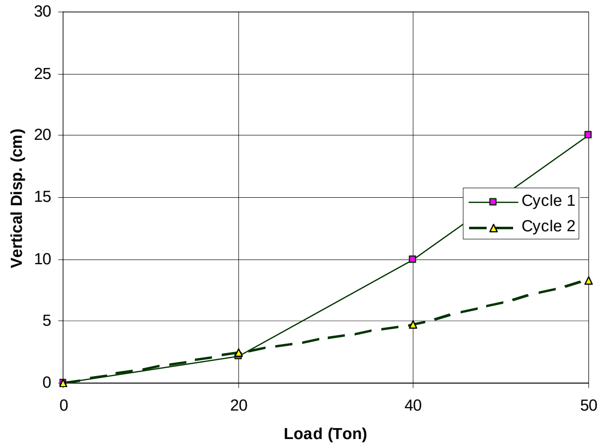


Figure-9. Vertical loading of un-rendered bale sample 1 group2 exposed to two cycles of loading.

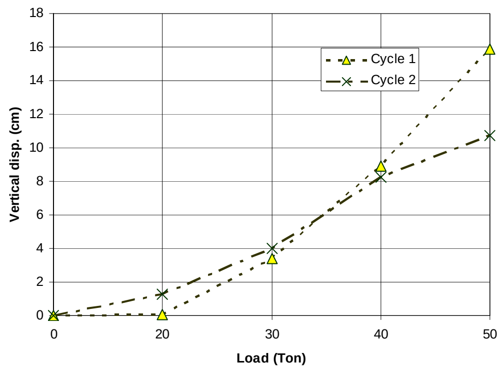


Figure-10. Vertical loading of un-rendered bale sample2 group2 exposed to three cycles of loading.

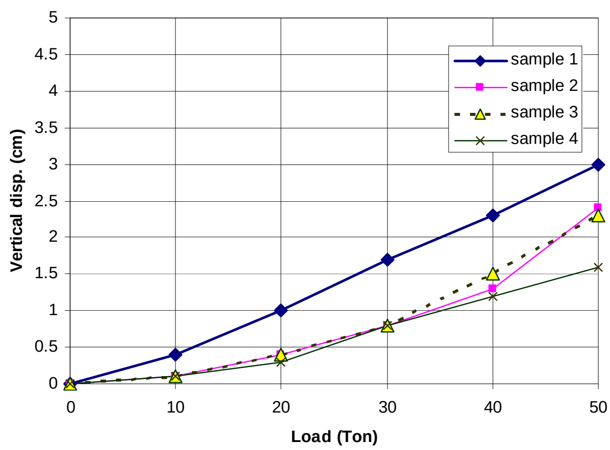


Figure-11. Vertical displacement of four samples of un-rendered single bales group3.

7. DISCUSSIONS AND CONCLUSIONS

All the samples under inspection of groups 2 and 3 which were compressed by private small sized iron factory compressing machines (type2) tied with sisal twine polypropylene string, met the density requirements specified with the California Straw Codes that insisted a minimum calculated dry density of 7.0 pounds per cubic feet (112 kg/m^3).

The moisture content of all the samples also met the codes safe maximum values for a building bale which did not exceed 20%.

Samples of bales group1 met the California baling codes and the Texas City codes requirements of dry moisture content as they did not exceed 20%. Whereas the density of bales of this group, that were compressed using the Cicoria baling machine, were far beyond the codes limits which are 112kg/m^3.

Displacement results agree with the physical properties of the investigated groups. The test results for each group were presented in the manner of load versus displacement (shortening). These graphs reveal some interesting notes regarding the load carrying behavior for each group.

As for bales group 1, which were very loose by visual inspection, samples 1 and 2 were unexamined while a maximum recorded strain of value 25 cm for sample 3, and 17 cm for sample 4 were obtained under loading level 50 ton. This great variance in the displacement behavior of this group of bales together with the variance in its weights, density and string tightness, expresses non consistency of the samples obtained from compressing machine type 1 (Cicoria). This indicates that this type of machines which is commonly owned by the government produce bales that only serve the main purpose of collecting the maximum amounts of available straw just to save storage areas on the cultivated lands. According to this analysis, the Cicoria compressing machines are far from giving consistent and adequate compressible bales to meet the specifications required for construction.

Bales of group 2 with its higher density, but poor outer shape, gave better strain values than group 1, although still considered out of acceptability range according to its displacement behavior due to slight irregularities in their dimensions. The bales were loaded for more than one cycle of loading to investigate the effect of re-loading on the vertical displacement of bales compressed with baling machines type2. The samples showed high consistency when loaded up to 20 tons for sample 1 and 40 tons for sample2 after which great variance in the displacement values occurred. The maximum vertical displacements reached 20 cm for sample 1 and 16 cm for sample 2 when loaded to 50 tons in cycle 1. Relatively lower displacement values were obtained for the two samples which reached 8 and 11 cm respectively under cycle 2 of loading.

From test results it can be concluded that the irregularity in the sides' height of straw bales group 2 affected the displacement properties of the bales although they met the physical requirements of density, weight and moisture content.

Samples of group type 3 were also compressed using the baling machine type 2. The displacements of all the bales of this group showed the highest consistency with maximum displacement of 3 cm under loading 50 tons indicating high efficiency in the baling mechanism of this group of bales.

It is recommended to ensure by visual inspection that the bales used for building are of consistent dimensions and of high tightness with a twine polypropylene string at distances of approx. 1/3 the bale width. A moisture meter is used to measure the dry moisture content of the bales which should not exceed 20% of the bale weight. The minimum density of the bales used for building is 112kg/m^3. These specifications highly encourage the government to use the small sized iron factory compressing machines (type 2) for the mass production of the bales used for construction.

REFERENCES

1. Magwood C., Mack P. and Therrien T. April 2005. More Straw Bale Building: A Complete Guide to designing and Building with Straw. New Society Publishers, Canada.

2. King B. 2006. Design of Straw bale Buildings: The State of the Art. Published by Green Building press, USA.

3. Austin City Code-Volume II, Title 25 Land Development \Chapter 25-12 Technical Codes \Article: Uniform Building Code\25-12-3 Local Amendments to the Building Code.

4. California straw bale codes.

5. Garas *et al*. 2008. Straw Bale Load Bearing Walls versus Traditional Brick Walls: An Economic Study. A paper under refereeing in the Journal of Environmental management.

6. دراسة تصنيع 2006: اعادة تدوير قش الارز في صناعة مواد البناء
د.م /تامر محمد أكمل رفعت "طوب المباني
قسم العمارة – الجامعة الحديثة