RESISTANCE TO COMPACTION/BALING OF RECYCLABLE CARDBOARD WASTE USING STATIONARY HORIZONTAL PRESSES

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Abstract: The paper presents the resistances to the formation of a bale of recyclable cardboard, in the ten stages of its formation, up to binding, as well as on each stage separately, for the pressing phase and for the expansion phase, until the start of a new cycle, including the mass variation of the bale in formation. It also presents the energy accumulated in the bale for each phase of its formation, and the total energy required for its formation. The presented data can be used both by the builders of balers for pressing and baling recyclable waste, and by their users to make the best settings.

Keywords: recycling, cardboard waste, compaction/baling, horizontal press, compaction energy

1. INTRODUCTION

For a long time, the management of recyclable waste poses special problems to mankind, implicitly to the companies that deal with their collection and recycling. This means that the management of these categories of waste is a complex process that begins with their collection, transport and recovery in the form of bales, each stage requiring time and costs, [1-5]. The problem of reducing the volume of bulky waste so that it could be handled more easily was quickly understood by machine builders, who devised suitable compaction and baling equipment's [6]. The capacity of these equipment's (presses) falls within a wide range of values, depending on the volume of waste processed. Thus, there are stationary vertical presses with intermittent operation, with manual feed, of different capacities, as well as stationary horizontal compactors/balers with continuous feed and operation. However, these installations also work cyclically, because the formation of a bale from recyclable waste requires repeated feeding and compaction, until the regulated volume of the bale is reached [7].

Whatever the field of activity (industry, trade, warehouses, supermarkets, offices etc.), paper and cardboard waste is found in significant quantities. Cardboard is one of the most commonly used packaging materials and comes in a variety of forms [8]. It is a recyclable material that can be relatively easily recycled by paperboard factories to save money and resources, instead of being incinerated or landfilled. Products that are made from recycled cardboard include several categories of cardboard boxes, for transport, storage and archiving, egg cartons and honeycomb cartons, shoe boxes, decorative boxes etc.

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Purchasing a paper and cardboard waste compactor and baler is feasible mainly for chain stores, but it can also be cost-effective for sorting stations near landfills. The results of external research have shown that cardboard recycling is economically feasible.

From worldwide research [1], results show that most businesses report producing significant amounts of cardboard waste, with 83 % of businesses reporting that between 30-50 % of their waste consists of cardboard. Similarly, almost 92 % of companies report that between 30-50 % of their waste consists of plastic film. These materials are mainly used as secondary packaging - packaging that the retailer is expected to open to sell packaged products to the consumer [7, 8].

However, it is suspected that there is an under-reporting of the total waste produced because not all waste is deposited. Another possible reason for the lack of accurate reporting of the actual volume of waste is that not all packaging waste ends up in the bins, and in particular secondary waste such as cardboard. After collection, cardboard waste, generally having a large volume, is compacted and baled to make it easier to transport for processing and recycling (Figure 1) [9-14]. Horizontal or vertical compacting, baling and binding presses, with discontinuous or continuous flow, greatly simplify waste management.

Fig. 1. Bales resulting from cardboard compaction.

Different variants of compaction systems have been designed, tested and verified for different applications.

The paper presents the process of forming bales from recyclable cardboard waste and the resistances encountered by the piston of the horizontal press for compacting and baling, respectively tying, the formed bales. The average values of the force (pressure) in the main hydraulic cylinder of the press with continuous operation and sequential feeding of the pressing chamber are shown, as well as the variation of the bale mass in the ten forming sequences. The amount of mechanical energy stored in a bale during its formation is also presented. In addition, the correlation of the force in the main hydraulic cylinder with the displacement time during the feeding phase of the press chamber is presented.

2. EXPERIMENTAL SETUP

In the case of cardboard and paper products things are a little simpler than when baling plastic, and the choice of press is important. On stationary horizontal presses with continuous flow, large quantities are needed for the press to function properly and efficiently. A MAC 107 horizontal press with a medium production capacity was used for the experiments, where a high quality of the baled product is obtained. Horizontal presses for the compaction and baling of bulky, recyclable waste are designed to ensure all the necessary flow, from the supply of bulk waste to the discharge of tied bales. It is usually used in transfer stations and landfills, where these materials are ultimately recovered. Of course, the baling of waste can also be done to maximize the use of a storage space. Materials are pressed into high-density parallelepiped bales to reduce storage space and for easier handling and transport with minimal loss. The length of the bales is selectable, the bales being tied automatically when it is reached.

The method of making bales from bulky waste on presses with continuous horizontal flow, with discontinuous feeding, involves several loading batches, the bale being kept pressed at the time of tying with metallic or plastic wire, on one side of the press piston, and on the other hand by the previously formed bales remaining in the outlet channel of the press.

The press consists of the press body, the main hydraulic control block, the pressing chamber, the pressing carriage, knife and counter knife, the feeding basket, the binding device, the counter pressure system and, if necessary, the wrapping device. The press chamber and the lower or upper plates are made of Hardox, a superior and wear-resistant material. The body of the press is built from rigid frames, articulated between them, being equipped with the pump group and the 2 hydraulic compaction cylinders (Figure 2).

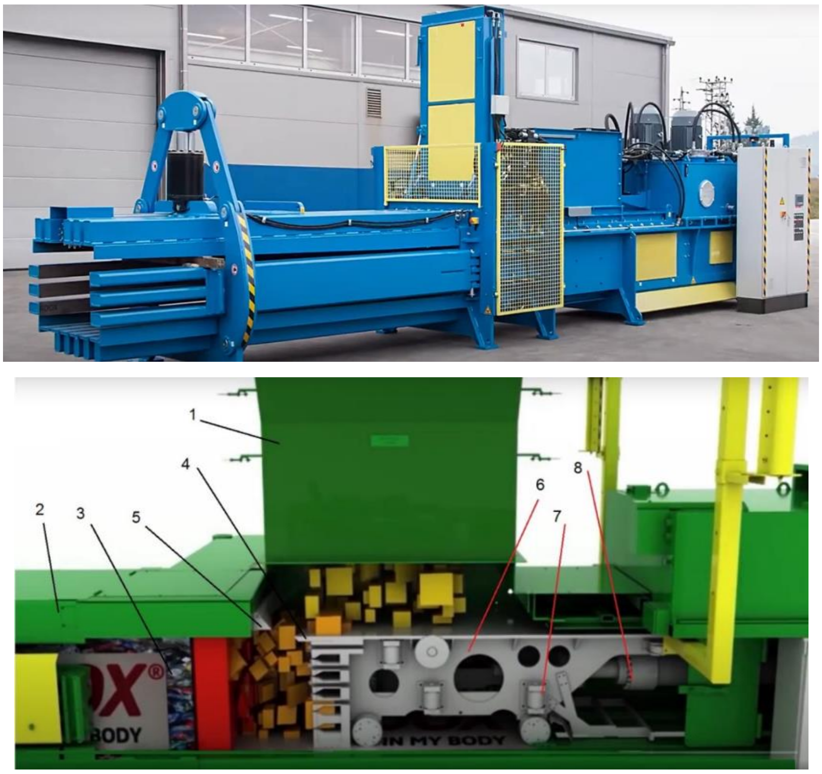

Fig. 2. Horizontal press for bales from recyclable waste: a) general view; b) section through the compaction chamber: 1 – supply bunker; 2 – exhaust channel; 3 – compaction chamber; 4,5 – knife-counter knife for cutting the material; 6 – pressing/compaction piston; 7 – piston lateral guide rollers; 8 – compaction piston drive cylinder.

Recyclables are fed discontinuously into the press's receiving hopper and fed into the compaction chamber, where a high-powered ram picks them up and feeds them, batch by batch, into the horizontal, rectilinear pressing chamber. Compaction occurs under the effect of piston pressure and the opposing resistance of previously formed bales in the exhaust channel, but mainly due to the pressure exerted by a high-power hydraulic cylinder and yoke counter-pressing mechanism. It acts on the side walls of the baling chamber and on the upper one which are formed by rigid bars articulated to the bale channel.

Depending on the settings on the control panel, the carriage of the press plate, translates the volume of waste and portions it with the help of the knife and counter knife, pressing it into the existing counterfront of the previous bale. Depending on the type of waste, the bale tends to be elastic and return to its original shape (for example, in the case of PET bottles) or has a plastic behavior in the case of aluminum cans, less so in the case of cardboard waste (which has a mixed behavior).

In the experiments carried out on cardboard waste, the formation of a bale was carried out in 10 steps with relatively identical volumes of material, the resistances encountered at the cylinder of the pressing piston being also, in principle, identical (Figure 3). The dimensions of the press feed chamber are L x l x h = 1.2x1.1x0.75 m (0.990 m^3), and the dimensions of the press channel are l x h = 1.1 x 0.75 m, piston stroke being of 1.3 m.

Fig. 3. The counter-pressure mechanism of horizontal balers for bulky recyclable waste.

Therefore, the experiments consisted in determining the resisting forces the formation of a bale from recyclable cardboard waste, when feeding the press in ten relatively identical charges, both on the active stroke of the compacting piston and on the return stroke, when the forces on the piston are given of the relaxation of the pressed waste in the previous stages. The energy stored in the bale for each cycle of the bale forming process is also determined.

3. RESULTS AND DISCUSSION

The parameters of the compaction process measured during the formation of a bale from cardboard waste are presented in Table 1 and are interpreted graphically according to Figure 4. The experiments showed that the 10 batches of material run quickly, with each batch being fed, pressed and compacted in 12 seconds (total time 120+6 seconds).

Table 1. Stroke and pressure in main CH vs. time to form cardboard bales.

Time, s	Piston displacement, m	Pressure in CH, bar			
		Compaction 1	*Compaction 1I*	*Compaction 1II*	*Compaction VI*
0.0	0	0	0	0	**0**
0.5	0.1	5	5	**5**	5
1.0	0.2	5	10	5	5
1.5	0.3	10	10	10	10
2.0	0.4	15	15	15	20
2.5	0.5	20	15	20	25
3.0	0.6	25	25	25	30
3.5	0.7	35	35	35	55
4.0	0.8	40	45	45	60
4.5	0.9	60	60	60	70
5.0	1,0	70	75	70	85
5.5	1.1	80	80	80	90
6.0	1.2	90	90	90	40
6.5	1.1	30	30	30	35
7.0	1,0	20	20	20	15
7.5	0.9	10	10	15	10
8.0	0.8	5	5	10	5
8.5	0.7	5	5	5	5
9.0	0.6	5	5	5	5
9.5	0.5	5	5	5	5
10.0	0.4	5	5	5	5
10.5	0.3	5	0	5	0
11.0	0.2	0	0	5	0

11.5	0.1	0	0	0	0
12.0	0	0	0	0	**0**

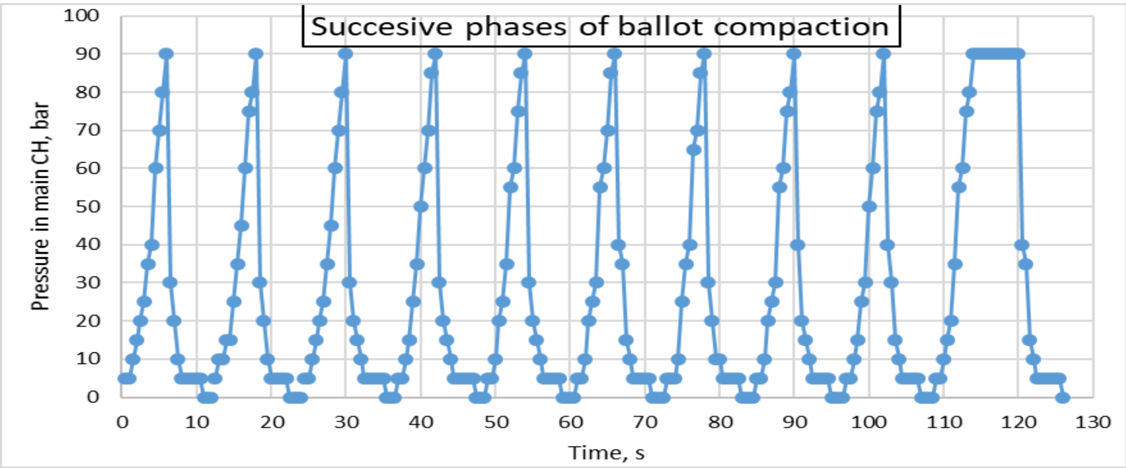

Fig. 4. The stages of cardboard bale formation and the force in the hydraulic cylinder versus time.

It can be easily observing the phases of compacting the volume of material fed in front of the pressing piston, as well as the phases of its withdrawal in order to execute a new work cycle. Also, at the last stage, the hydraulic cylinder remains under pressure for enough time (5-10 seconds) to tie the bale. The pressure in the main CH also depends on the regulated pressure on the CH of the pressing channel which is kept relatively constant at the value of 25 tf, with pauses of about 2.5 seconds to release the already formed bale and allow it to pass through the channel to the outlet.

From the analysis of a carton pressing work cycle, a relatively continuous increase in the compaction force is observed in the first half of it (6 seconds), until the maximum pressing force is reached, with some jumps and variations due to the non-uniformity of the material being pressed.

In the second part of the cycle (the next 6 seconds), when the hydraulic cylinder retracts to pick up a new portion of material, the force in the hydraulic cylinder decreases to zero. In the first 0.5 seconds of piston withdrawal, the decrease is sudden, followed by a slower decrease to a value of about 10 tf, with a plateau at this value of about 2.5 seconds, finally the force value decreasing to zero for the execution of a new cycle (Figure 4 and Figure 5).

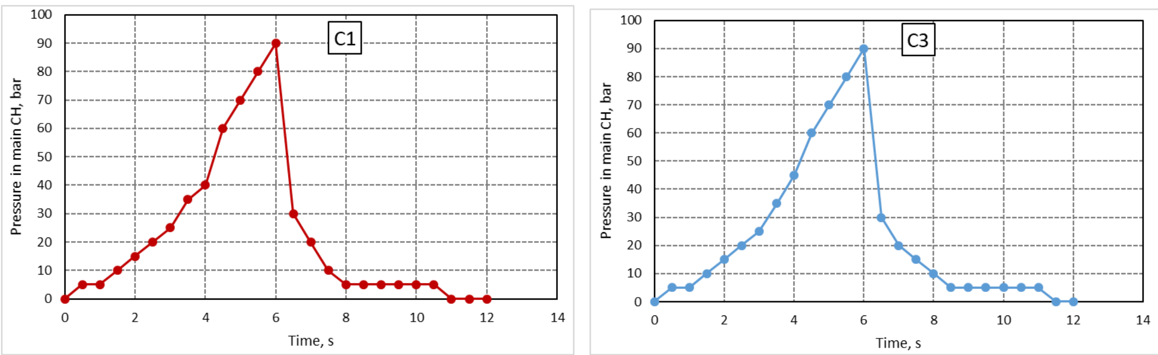

Fig. 5. Variation in time of the force in the hydraulic cylinder for cycles 1 and 3 of baling from recyclable cardboard waste.

Both Figure 4 and Figure 5 show the similarity between the compaction stages, the characteristics of the material to be compacted and the amount of recyclable cardboard on each batch being relatively constant.

In the Figure 6 are presented mass variation during bale formation (for the 10 loading batches).

To determine the energy consumption in the phases of forming the recyclable cardboard bale, it is necessary to graphically plot the force curves in the compression cylinder - piston displacement, as shown in Figure 7, for the first batch (stage) of supply.

For this period of bale formation (Figure 7), the calculations showed that the energy consumed in the compaction phase is about 42.0 tf·m, and in the withdrawal phase the energy consumed is 13.0 tf·m (for second loading with material). So, the mechanical energy stored in the bale (at this stage) is 29.0 tf·m (ie about 29.0 kJ). By assuming that all 10 phases of bale formation consume relatively the same energy, it follows that the energy consumed to compact and form a bale of recyclable cardboard (in 10 loading stages) is about 280-300 kJ, which is about 0.77-0.83 kJ /kg specific compaction energy stored in a bale (for a bale with an average mass of 360 kg) (Figure 6).

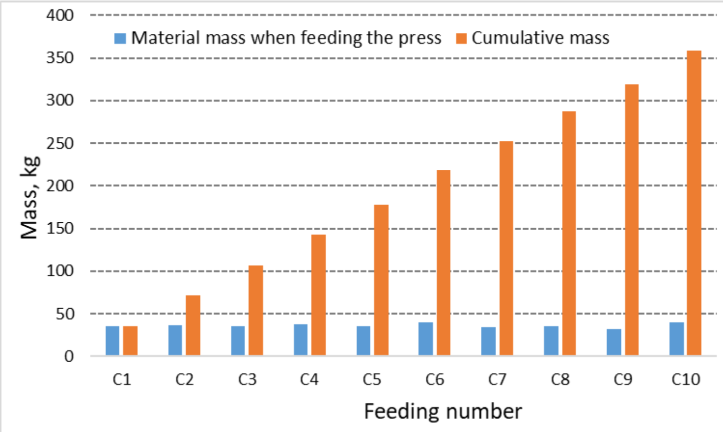

Fig. 6. Mass variation during bale formation (for the 10 loading batches).

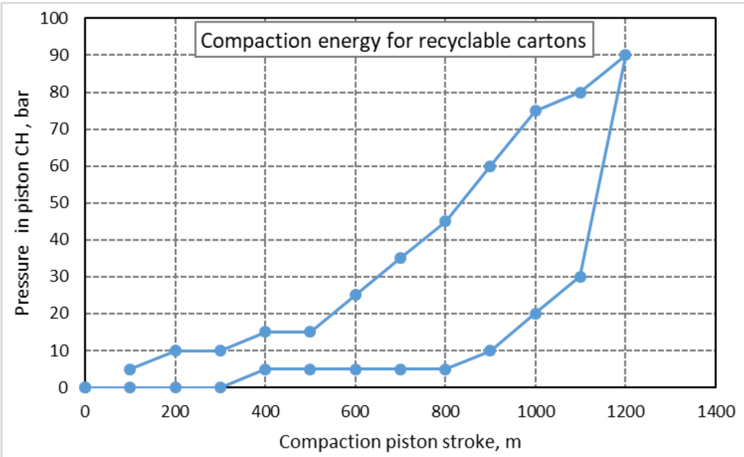

Fig. 7. The variation of the force in the working cylinder versus the displacement of the compression piston, in the first phase of forming a bale of recyclable cardboard.

The energy consumed in the operations of sectioning and isolating the material in the pressing chamber, in each cycle of bale formation, is included in the compaction-pressing energy, as in the case of bale formation from other recyclable waste.

To establish the correlation between the main parameters of the recyclable waste compaction process, the regression analysis of the correlation between the pressure in the main (compaction) hydraulic cylinder and the time in which the compaction plate moves until reaching the regulated maximum pressure was made. Regression analysis charts for two of the ten batches of bale formation are shown in Figure 8.

A linear degree of correlation of the two parameters is found, with a relatively slow slope. The other parameters of the regression analysis are specified on the graphs in the figure, respectively a correlation coefficient R^2 with values above 0.9 in all cases analyzed.

However, as can be seen from the graphs in Figure 8, there are important deviations from the linear trajectory of the piston, mainly due to the inhomogeneity of the material subjected to compaction and its behavior during compaction. It is appreciated that the cardboard waste has random positions in the press chamber, being arranged either parallel to the direction of movement of the piston, or perpendicular or oblique, which leads to random resistances encountered by the main piston of the press and, therefore, by the hydraulic cylinder of operation.

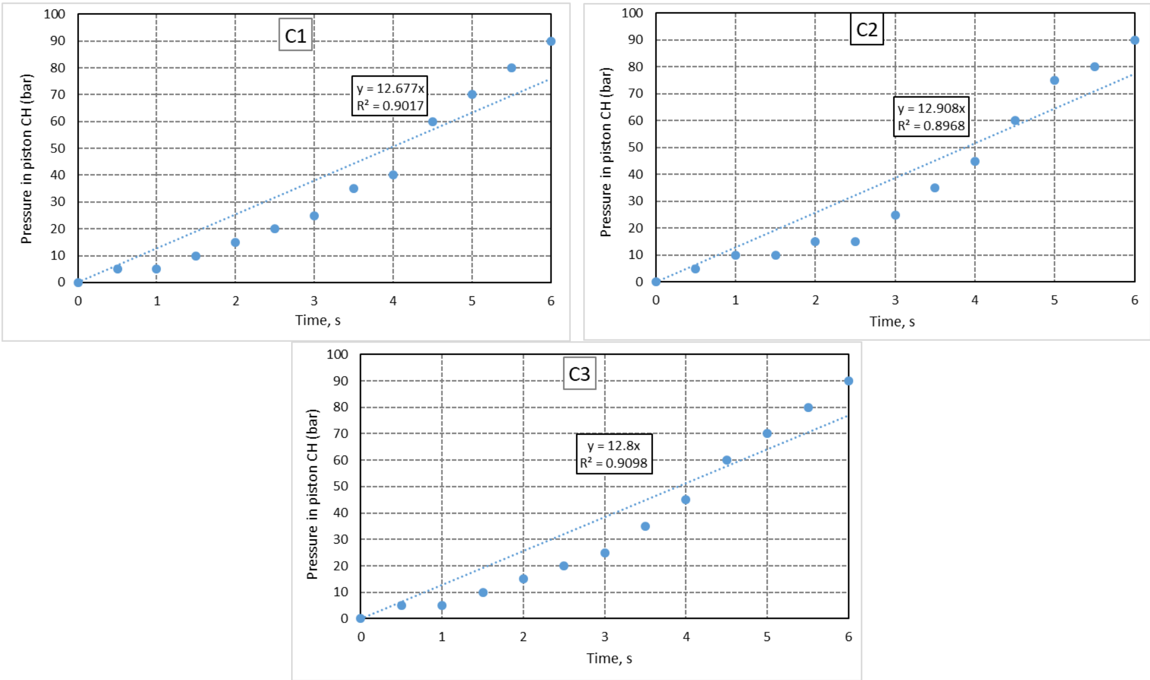

Fig. 8. Analysis of the degree of correlation between the pressure in the working CH and the travel time.

Compaction takes place in several batches, the process being similar to that of agricultural presses for straw and hay, after each feeding (batch) a pressing is carried out with the help of a large piston, so that during the pressing phase the tensions in the compacted material increase, while in the withdrawal phase the material expands slightly and the resistances (tensions) decrease to zero.

4. CONCLUSIONS

The formation of a bale is generally carried out in ten similar stages (the number is adjustable), at the last stage the press piston remains on the pressing phase for a few seconds to enable the binding system to finalize the formation and binding of the bale. The bales, already formed and tied, remain in the exhaust channel for a longer time, depending on its length and the pressure exerted on them by a hydraulic system acting from the top and sides.

For a bale of recyclable cardboard with an average mass of about 360 kg, the energy consumed for compaction and forming (in 10 loading stages) is about 280-300 kJ, which represents about 0.77-0.83 kJ/kg specific stored compaction energy in the bale.

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