

# Enhancement in a Mechatronic Aluminum Beverage Cans Recycling Machine

H. M. El-Zomor, M. Hany

**Abstract**—Recycling of aluminum beverage cans is an important issue due to its economic and environmental effect. One of the significant factors in aluminum cans recycling process is the transportation cost from the landfill space. An automatic compression baler (ACB) machine has been designed and built to densify the aluminum beverage cans. It has been constructed using numerous fabricated components. Two types of control methodology have been introduced in this ACB machine to achieve its goal. The first is a semi-automatic system, and the second is a mechatronic system by using a Programmable Logic Control (PLC). The effect of single and double pre-compression for the beverage cans have been evaluated by using the PLC control. Comparisons have been performed between the two types of control methodologies by operating this ACB machine in different working conditions. The double pre-compression in PLC control proves that there is an enhancement in the ACB performance by 133% greater than the direct compression in the semi-automatic control. In addition, the percentage of the reduction ratio in volume reaches 77%, and the compaction ratio reaches about four times of the initial volume.

**Keywords**—Aluminum can recycling, Fully automatic machine, Hydraulic system control, Multi-compression.

## I. INTRODUCTION

LANDFILL remains the simplest and the most commonly used method for disposing municipal solid waste (MSW) [1]. The quantity of gas that a MSW generates is influenced by the type and age of the waste buried in the landfill. The average percentage of gas by volume is about 40-60 % methane and 40-60 % carbon dioxide [2]. As a result of these gases, there is a concept for the developing countries to changes its policies to achieve the high-performance countries. One of these policies is the transformation from the waste collection in the landfill to energy production from waste, as shown in Fig. 1 [3].

The electrical energy embedded in metallic aluminum can be considered as “energy bank” or “energy storage” [4]. As the production of primary aluminum requires about 45 kWh/kg of energy, and emits 12kg of CO<sub>2</sub>, while the recycling of aluminum requires only 2.8 kWh of energy and emits 0.6kg of CO<sub>2</sub>. Thus, 95% of energy and environmental emissions have been saved during the recycling. Aluminum beverage cans save a huge energy; moreover, the greenhouse gas emissions are dramatically reduced [5], [6]. So the recycling economy of aluminum beverage cans is a new type of development model

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and economic growth mode [7].

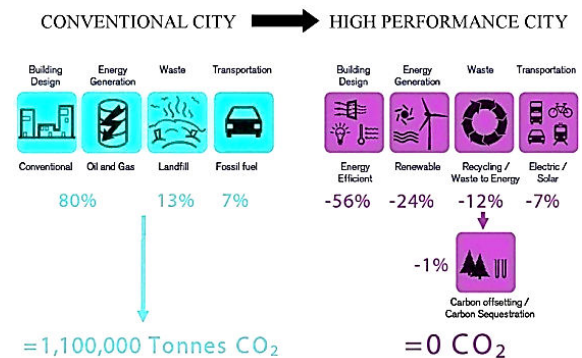


Fig. 1 Concept of transformation from conventional city to high performance one, [3]

During the last decades, interest has been focused on recycling of aluminum cans. Recycling of 1kg of aluminum beverage cans save up to 8kg of bauxite, 4kg of chemical products and 14 kWh of electricity [8]. In addition, recycling of aluminum cans wastes help freely up space, recycling of one ton of aluminum cans saves 10 cubic yards of landfill space. [9]. Due to the people’s awareness about the importance of recycling, the aluminum beverages' cans recycling enlarge dramatically at the last decades, as shown in Fig. 2.

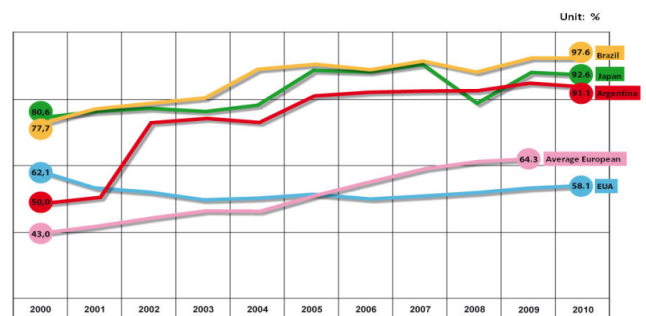


Fig. 2 The growth in the rating of cans recycling [10]

Although the augmentation of aluminum beverages cans recycle proportion, there are several barriers that hinder the expanding process of aluminum recycling; the most important factor is the high-energy costs in transporting waste materials [11]. Transportation of municipal solid waste takes a major portion of budget, and the unplanned transportation system may cause huge loss of funds [12].

The waste density is an important measure used to define

the number, capacity of waste storage, and collection facilities required. Based on waste density and the capacity of trucks, the amount of waste collected can be calculated. The densification performance can be measured by the percentage of volume reduction;

$$\text{Percentage of volume reduction} = \frac{(v_i - v_f)}{v_i} \quad (1)$$

and also by compaction ratio;

$$\text{Compaction ratio} = \frac{v_i}{v_f} \quad (2)$$

where;

$v_i$  = Initial volume of cans before compaction

$v_f$  = Final volume of cans before compaction

It is fair to say that, from all the last review, we found that more effort needed to increase the rate of aluminum beverage cans recycling. An ACB machine has been designed and fabricated to densify the aluminum beverage cans to take the advantages of the aluminum can recycling.

## II. MATERIALS AND METHODOLOGY

The ACB machine consists of three main systems; firstly, a metallic frame has been designed and fabricated to assemble the whole components of the ACB machine. Secondly, hydraulic system; which is the power source for the densifying process. Finally, in order to automate the hydraulic system, two control strategies have been utilized; the first was through an electronic circuit by the aims of relays and limit switches. The second was through a Programmable Logic Control (PLC).

### A. Design Inputs

The first phase during the design process of the ACB machine was to identify the needed force to densify one or more beverage cans.

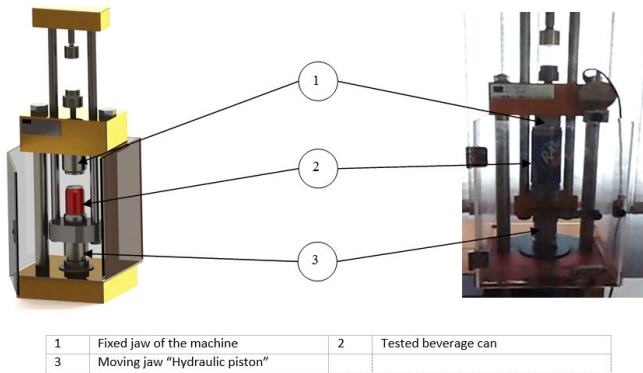
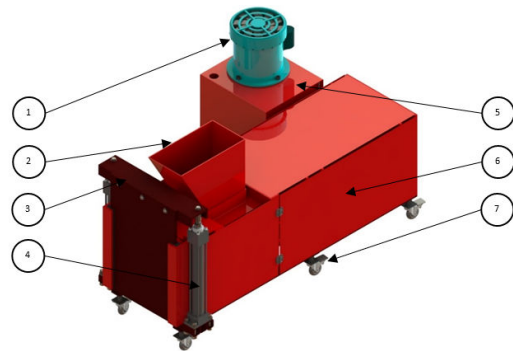


Fig. 3 The beverage can tested in the tension compression machine

Several experiments have been carried out to determine the amount of force required to densify the beverage cans. A standard tension compression test machine has been used as shown in Fig. 3. The results have been plotted to deduce the average force versus the beverage can's displacement. This calculated force is the first design input for the mechanical design of the metallic frame and the hydraulic circuit of the ACB machine.

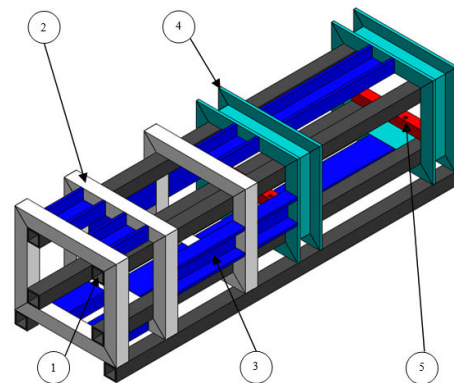
### B. Machine Frame

A metallic frame structure has been designed especially for this work with overall dimensions (1134 x 722 x 510) mm, as shown in Figs. 4 and 5. In order to design the metallic frame, a finite-element method software "SolidWorks" has been used. The frame design was prototyped several times accordingly to reliability, limitations, and factor of safety until achieving this design with minimum factor of safety (FOS) 3.09, as shown in Fig. 6.



1	Electric motor	5	Hydraulic tank
2	Hopper	6	Machine casing
3	Compression baler gate	7	Machine wheels
4	Piston gate		

Fig. 4 The proposed design for the ACB



Part Name	Item used	Cross section	colour
1 Main longitudinal beams	6	40x40x4	Black
2 Main beam for compression chamber	3	40x40x4	Grey
3 Cross member beams	13	80x40x8	Blue
4 Main longitudinal beam for hydraulic piston	2	80x40x8	Blue
5 Fixation of hydraulic piston	2	30x30x3	Red

Fig. 5 The final metallic frame design of the ACB machine

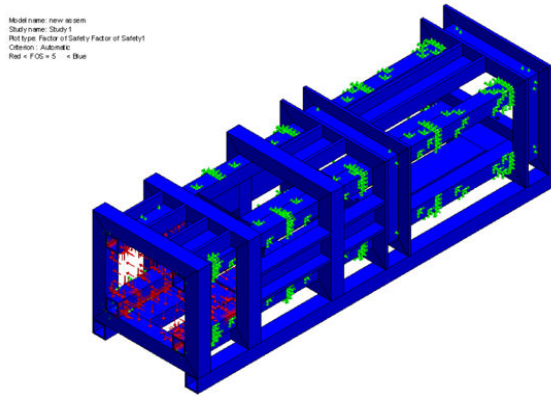


Fig. 6 The distribution of FOS below 5, showing the fixation and loading location

### C. Hydraulic Circuit

Hydraulic circuit has been designed for the ACB machine based on compression of about 17 beverage cans in each cycle. It has been modeled by using the “Automation Studio” software. The main system components are; 2 HP single phase electric motor, gear pump, one compression piston of diameter 6.35cm, and two gate piston of diameter 3.81cm, pressure gauges, and two directional way valves, as shown in Fig. 7.

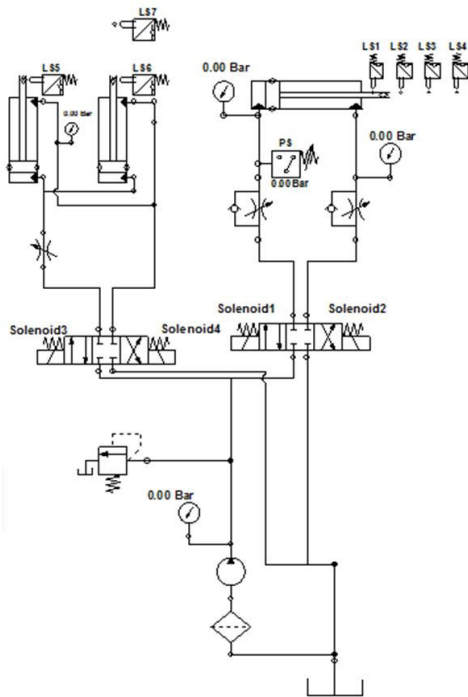


Fig. 7 The hydraulic circuit design and simulation

The hydraulic circuit has two directional way-valves; the first valve (1) includes (solenoid 1 and 2) is used by the compression piston, and the second valve (2) includes (solenoid 3 and 4) is used by the gate pistons. Six limit switch and one pressure switch have been used in this circuit to simulate the motion of the compression piston and the gate pistons.

### D. Control Methodology

The control methodology of the ACB machine is divided into two sub-systems. The first is the classic electric circuit (semi-automatic control) which depends on four push buttons and two limit switches as an input for the directional control valve, as shown in Fig. 8. The second system is the (fully automatic control), by using seven limit switches and one pressure switch as sensors for the Programmable Logic Control (PLC), shown in Fig. 9.

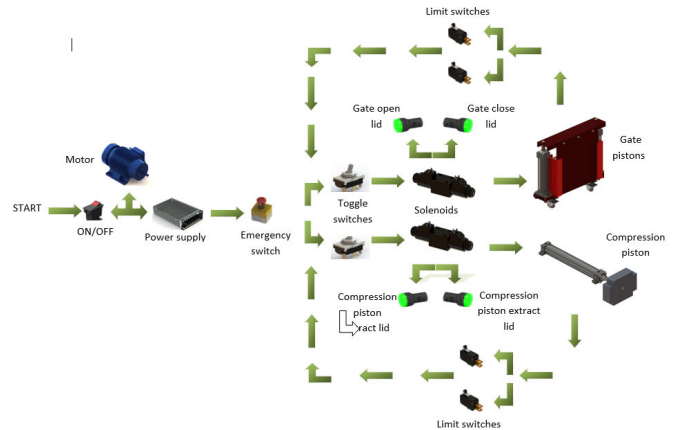


Fig. 8 Block diagram for the semi-automatic control methodology

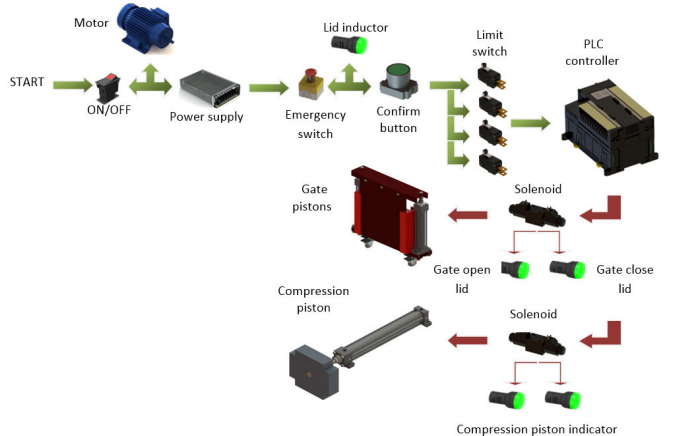


Fig. 9 Block diagram for the fully-automatic control methodology

The ACB machine has been operated by a control box to select the desired control methodology, as shown in Fig. 10. A real photo for the ACB machine is finally shown in Fig. 11.

### III. RESULTS

The designed ACB machine has proven its capability allows conducting several types of measurements aimed to find out the optimum type of control methodology for best volume compaction.

Tests that can be carried out using the ACB machine are mainly;

- Reduction ratio in can's volume vs. number of cans per cycle at various operating pressures.

- Compaction ratio vs. number of cans per cycle at various operating pressures.
- Effect of one pre-compression and two pre-compression in each case.

Several number of tests have been performed by densifying beverage cans with traditional semi-automatic control “direct compression” and another type of testes by using fully automated control by the aim of PLC “one pre-compression” and “two pre-compression”.

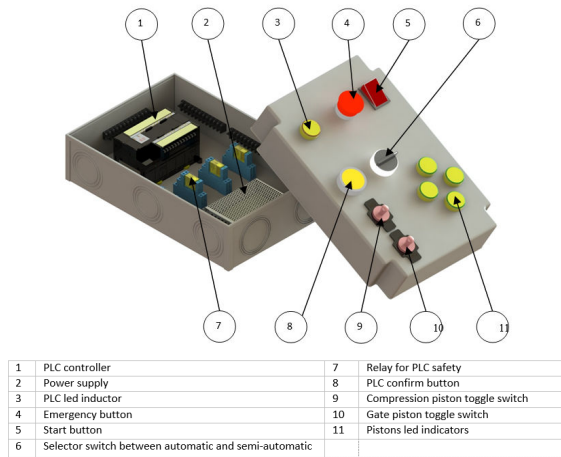


Fig. 10 The main component of the ACB machine control box



Fig. 11 A real picture for the ACB machine



Fig. 12 Samples of real picture for the beverage cans after the densification process

Figs. 13-15 show the effect of the reduction ratio in volume versus the number of tested beverage cans at various operating pressures. Fig. 13 shows the direct compression by using the semi-automatic control, while Figs. 14 and 15 show the effect of one and two pre-compression. The results show that the operating pressure 50 bar achieve the maximum reduction in volume and especially in the 13 and 15 cans per cycle in the two pre-compression.

Figs. 16-18 show the effect of the compaction ratio versus the number of tested beverage cans at various operating pressures. Fig. 16 shows the direct compression by using the semi-automatic control, while Figs. 17 and 18 show the effect of one and two pre-compression by using the fully automated PLC. The results show that; at operating pressure 50 bar the maximum compaction reaches satisfied values on all the tested samples and especially in the 10, 13 and 15 beverage cans per cycle in the two pre-compression.

Fig. 19 shows the percentage of improvement in the one pre-compression and two pre-compression with respect to the direct compression. A sample of the 19 tested cans per cycle showed an improvement of 133 % in performance at 50 bar better than the direct compression.

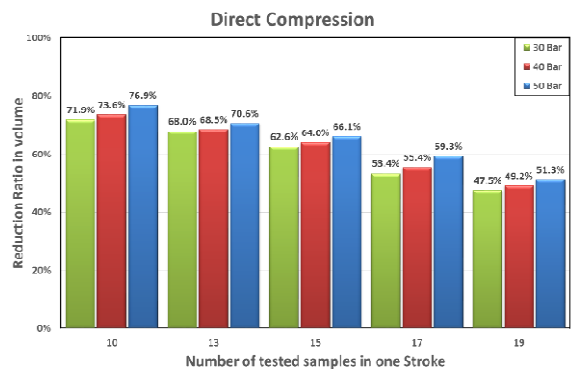


Fig. 13 The reduction ratio in volume for direct compression

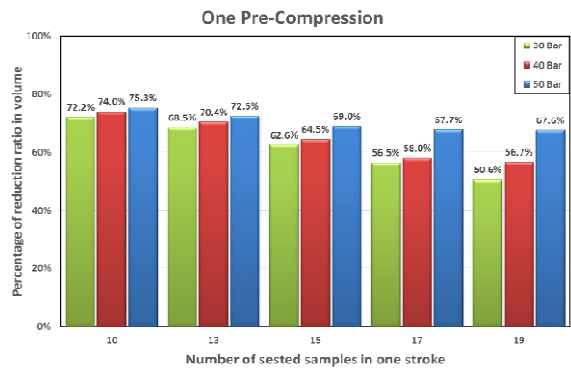


Fig. 14 The reduction ratio in volume for one pre-compression

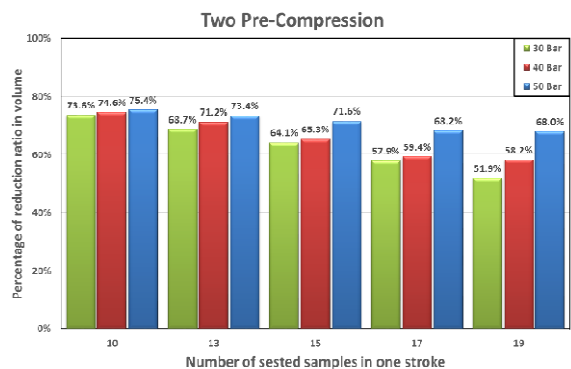


Fig. 15 The reduction ratio in volume for two pre-compression

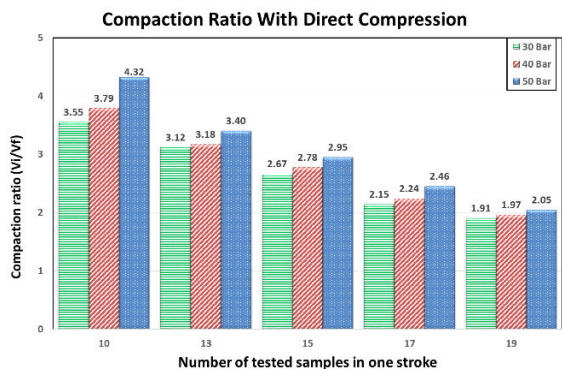


Fig. 16 The compaction ratio with direct compression

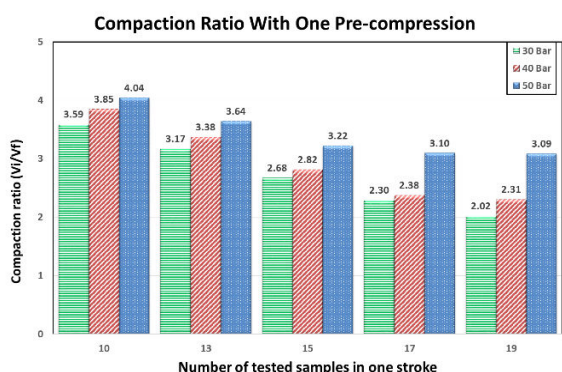


Fig. 17 The compaction ratio with one pre-compression

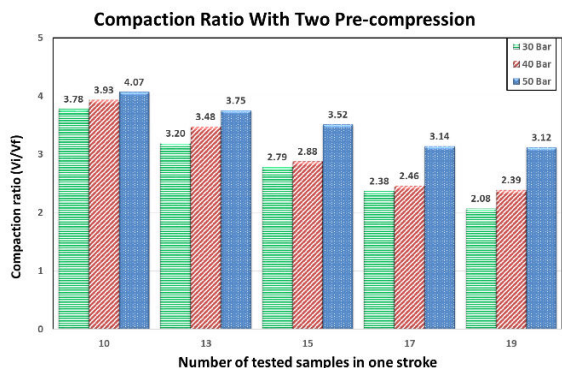


Fig. 18 The compaction ratio with two pre-compression

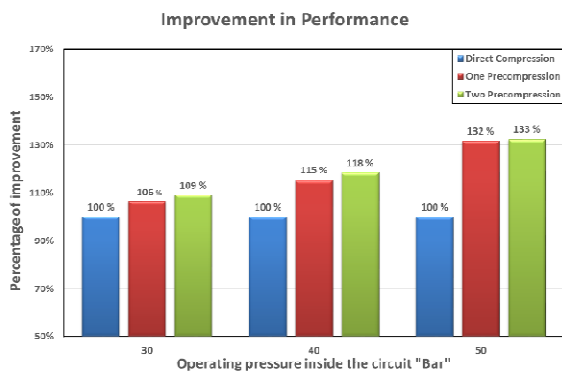


Fig. 19 The improvement of performance of one and two pre-compression with respect to direct compression at 19 cans sample.

#### IV. CONCLUSION

Enhancement of waste production by using this ACB machine, particularly increasing aluminum recycle rates leads to several important conclusions:

1. After several trials in this sample model of ACB machine, we concluded that the optimum condition in volume reduction of beverage cans was from 15 to 17 cans per working cycle at pressure 50 bar and by using the programmable logic control.
2. Avenues from the aluminum recycling of beverage cans should be encouraged for its massive economic, energy, and ecological advantages to the communities and to the aluminum industry. In our case; assuming the ACB machine works 22 days per month, and 12 hours per day and operated by the fully automatic mode "PLC" by 15 beverage cans of mass 14.5 grams each for the 330mL. It was measured that the complete cycle duration is about 60 seconds, the machine capacity will be of 13kg/hr, and then the mass per month is 3.42 ton.
3. The handling, storage and processing of solid wastes have a significant effect in the solid waste management system. In our case with the same operating conditions, at a certain number of operated cans, without densification the storage volume needs 78.1m<sup>3</sup>. While after the densification process, the storage volume will be reduced to 24.97m<sup>3</sup>.
4. Economic evaluation of the reduction in transportation cost results from the ACB machine by; a vehicle of capacity is 9m<sup>3</sup>; it can transfer about 24,338 cans in each job without densification. At the optimal operating condition for the ACB machine, the vehicle can transport 85,620 cans. Then the reduction in transportation cost is about three times and half.

It is possible to conclude that the aluminum can recycling reduces part of the consumption of natural resources, and the emissions associated the production stages.

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