International Journal of Education, Vocational and Social Science
https://e-journal.citakonsultindo.or.id/index.php/IJEVSS
E-ISSN : 2963 4954
IJEVSS

Analysis Of The Effect Of Air Pressure Variations On The Performance Of Pneumatic-Based Automatic Can Waste Pressing Machine Reviewed From The Press Force

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Abstract

This study was conducted to investigate the effect of air pressure variation and mold construction on the performance of an automatic pneumatic aluminum can press machine. The observed parameters included the final height of the can after pressing, piston movement time, and the percentage of volume reduction. The research used an experimental method by applying air pressure variations of 3.5 bar, 4 bar, 4.5 bar, and 5 bar. The tests were carried out using several mold designs, including a flat mold, a concave mold with a depth of 0.00050 m, and a concave mold with a depth of 0.00070 m. The piston stroke variations used were 0.008 m and 0.010 m. Three types of aluminum cans were used as test specimens, namely Nescafe, Lasegar, and Kratingdaeng cans.

The results showed that increasing air pressure affected the pressing process by increasing the force produced by the pneumatic system, resulting in a decrease in the final height of the cans.

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The differences in mold design also influenced the deformation results because the distribution of pressing force on the cans varied under each test condition. The best pressing performance was obtained using a 0.00070 m concave mold with a 0.010 m piston stroke. Under this condition, the Kratingdaeng can reached the lowest final height of 0.00750 m at an air pressure of 5 bar. Furthermore, the highest volume reduction was obtained from the Nescafe can with a reduction value of 93.4% using a flat mold at 4.5 bar pressure. Based on the experimental results, it can be concluded that air pressure, mold construction, and piston stroke length have a significant effect on the effectiveness of the automatic pneumatic aluminum can pressing process.

Keywords: Air pressure, pneumatic press machine, mold construction, volume reduction, aluminum can waste.

INTRODUCTION

Aluminum can waste has become one of the issues in waste management due to the increasing amount of waste generated from the high consumption of packaged beverages. Aluminum materials have a relatively slow decomposition process, causing environmental problems when they are not properly managed. In addition to reducing environmental quality, accumulated aluminum cans require a large storage area and can increase the difficulty of waste handling and transportation processes. Therefore, an effective method is needed to reduce the impact caused by aluminum can waste. One method that can be applied is a compaction process using a press machine. This process is intended to reduce the size and volume of cans so that they can be stored, transported, and recycled more efficiently.

The development of pneumatic technology has been widely applied in various industrial equipment, including waste pressing machines. Pneumatic systems utilize compressed air as an energy source to produce mechanical movement through a working cylinder. The application of pneumatic systems in pressing machines provides several advantages, such as simple construction, relatively low maintenance requirements, and the ability to produce fast and stable motion. In addition, pneumatic systems are considered safer compared to several other drive systems. Therefore, pneumatic technology has been widely developed for aluminum can pressing applications.

Several previous studies have investigated the influence of pneumatic system parameters on pressing performance. Ahmad et al. (2021) reported that air pressure variation affects the generated pressing force and the compaction results of aluminum cans. Similar findings were

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reported by Siregar et al. (2021), who stated that increasing pneumatic pressure can produce greater deformation on the pressed material. Putra and Wijaya (2021) also found that an automatic aluminum can press machine was able to reduce waste volume by more than 80%.

In addition to air pressure, the design of the pressing mold also affects the final result of the compaction process. Hidayat et al. (2022) explained that air pressure influences the movement speed and force generated by pneumatic cylinders. Pratama et al. (2022) stated that mold geometry plays an important role in determining the distribution of pressing force during the compression process. Furthermore, Nugroho et al. (2022) concluded that optimization of pneumatic systems can improve the efficiency of waste compaction processes. Kurniawan et al. (2023) developed an automatic aluminum can pressing machine and reported an improvement in pressing productivity. Saputra et al. (2023) found that higher pressure resulted in more significant deformation changes in aluminum cans. Harahap et al. (2023) also reported that the volume reduction of aluminum cans increased with increasing air pressure applied to the pneumatic system.

Further studies related to pneumatic pressing systems continue to be developed to obtain better compaction performance. Sembiring et al. (2024) stated that pneumatic press machines are effective for reducing aluminum can waste volume. Ramadhan et al. (2024) explained that deformation behavior during the compaction process can be influenced by material buckling phenomena. Meanwhile, Firmansyah et al. (2024) found that concave molds produced different deformation patterns compared to flat molds. Recent research by Syahputra et al. (2025) showed that the application of PLC-based control systems can improve the consistency of the pressing process. Lubis et al. (2025) reported that cylinder stroke length affects the final height of cans after compaction. Rahman et al. (2026) found that selecting an appropriate pneumatic pressure can produce higher volume reduction in aluminum waste.

Based on previous studies, air pressure, mold construction, and cylinder movement characteristics are important factors affecting the performance of aluminum can compaction processes. However, studies regarding the combination of air pressure variations of 3.5 bar, 4 bar, 4.5 bar, and 5 bar with different mold designs, including flat molds, inward-hole molds with a depth of 0.00050 m, and concave molds with a depth of 0.00070 m, in an automatic pneumatic aluminum can press machine are still limited. Therefore, this study was conducted to analyze the effect of air pressure variation and mold construction on the final height of cans, pressing time, and volume reduction of aluminum can waste.

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RESEARCH METHOD

Research Type and Approach

This research used an experimental method with a quantitative approach. The experimental method was selected because this study focused on examining the effect of several operating parameters on the performance of an automatic pneumatic aluminum can press machine. The variables investigated included air pressure variation, mold construction, and piston stroke length. The quantitative approach was applied because the data obtained from the testing process were measured directly and expressed in numerical values. The measurement results were then analyzed to determine the relationship between the independent variables and the pressing performance of aluminum cans. The observed parameters included the final height of the can after pressing, piston movement time, final volume of the can, and percentage reduction in volume.

Research Location and Time

The research was conducted at the Mechanical Engineering Workshop, Faculty of Engineering, State University of Medan (UNIMED), Willem Iskandar Street, Pasar V Medan Estate, Medan, North Sumatra, Indonesia. The research was carried out for 66 days, starting from April 1, 2026, until June 5, 2026. The activities during this period included preparation of research equipment and materials, testing of the pneumatic pressing system, data collection, data processing, and analysis of experimental results.

Research Variables

The research variables consisted of independent variables, dependent variables, and control variables.

Independent Variables

The independent variables used in this study were:

1. Air pressure variation

The air pressure applied to the pneumatic system consisted of:

- 3.5 bar
- 4.0 bar
- 4.5 bar
- 5.0 bar

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2. Mold construction variation

The molds used in the experiment consisted of:

- Flat mold
- Concave mold with a depth of 0.00050 m
- Concave mold with a depth of 0.00070 m

3. Piston stroke length

The piston stroke variations were:

- 0.008 m
- 0.010 m

Dependent Variables

The dependent variables measured in this research were:

- Final height of the aluminum can after pressing (m)
- Forward and backward piston movement time (s)
- Final volume of the aluminum can (m^3)
- Percentage reduction of aluminum can volume (%)
- Deformation changes of the aluminum can after pressing

Control Variables

The controlled variables maintained during the experiment were:

- Position of the aluminum can at the center of the mold
- Initial condition of the can (empty, clean, and without deformation)
- Type of aluminum material
- Condition of pneumatic components
- Environmental temperature during testing

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Research Equipment and Materials

Research Equipment

The equipment used in this study is presented in Table 2.1.

Table 1 Research Equipment

No	Equipment	Specification
1	Aluminum can press machine	Automatic pneumatic system
2	Pneumatic cylinder	Double acting, diameter 0.10 m, stroke 0.25 m
3	Air compressor	1–8 bar
4	Air regulator	0–10 bar
5	Solenoid valve	5/2 way, 24 VDC
6	Limit switch	Roller lever type
7	Digital caliper	Accuracy 0.00001 m
8	Digital stopwatch	Accuracy 0.01 s
9	Pneumatic hose and fitting	According to system requirements

Research Materials

The materials used were three types of aluminum beverage cans. The initial dimensions of the test specimens are shown in Table 2.2.

Table 2 Aluminum Can Test Materials

No	Can Type	Initial Height (m)	Initial Diameter (m)
1	Nescafe	0.13200	0.05064
2	Lasegar	0.10640	0.06124
3	Kratingdaeng	0.09142	0.06541

Pneumatic Aluminum Can Press Machine

The pressing machine used in this research is an automatic pneumatic aluminum can press machine. The working principle of the machine is based on compressed air supplied from the compressor. The air pressure is regulated and controlled through the pneumatic system to move the cylinder piston forward and backward. The piston movement generates pressing force that compresses the aluminum can inside the mold. The machine structure used in this research is shown in Figure 1

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Figure 1 Automatic Pneumatic Aluminum Can Press Machine

Pneumatic System Circuit

The pneumatic circuit consists of an air compressor, regulator, solenoid valve, pneumatic cylinder, and control components. The regulator controls the air pressure according to the test variation, while the solenoid valve controls the direction of piston movement. The pneumatic system circuit used in the aluminum can press machine is shown in Figure 2

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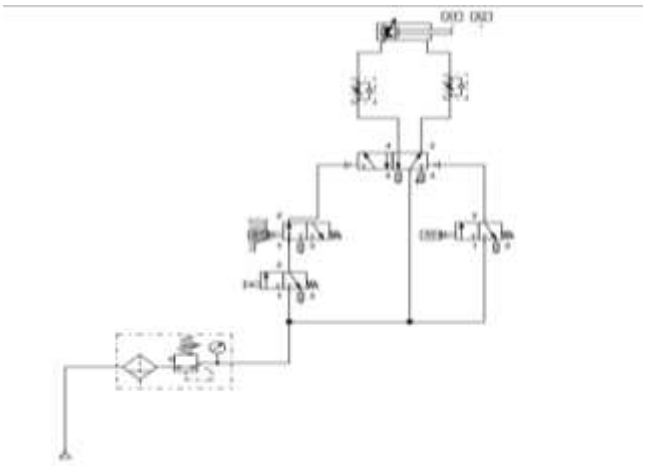


Figure 2 Pneumatic System Circuit of Aluminum Can Press Machine

Research Procedure

The research procedure was carried out through several stages, as shown in Table 2.3.

Table 3 Research Procedure

No	Research Stage	Activity
1	Equipment and material preparation	Preparing all equipment and materials required
2	Pneumatic system inspection	Checking pneumatic components to ensure proper operation
3	Air pressure setting	Adjusting pressure according to test variation (3.5–5 bar)
4	Mold installation	Installing the selected mold according to treatment
5	Piston stroke adjustment	Adjusting limit switch position to obtain required stroke
6	Test specimen placement	Placing aluminum cans at the center of the mold
7	Pressing process	Operating the machine until one pressing cycle is completed
8	Height measurement	Measuring final can height using digital caliper
9	Time measurement	Recording piston movement time using stopwatch
10	Volume calculation	Calculating final can volume
11	Repetition test	Repeating each test condition three times

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12	Data recording	Recording measurement results
13	Data analysis	Analyzing the effect of research variables
14	Conclusion	Determining conclusions based on analysis results

The research flow diagram is presented in Figure 3

Data Collection Technique

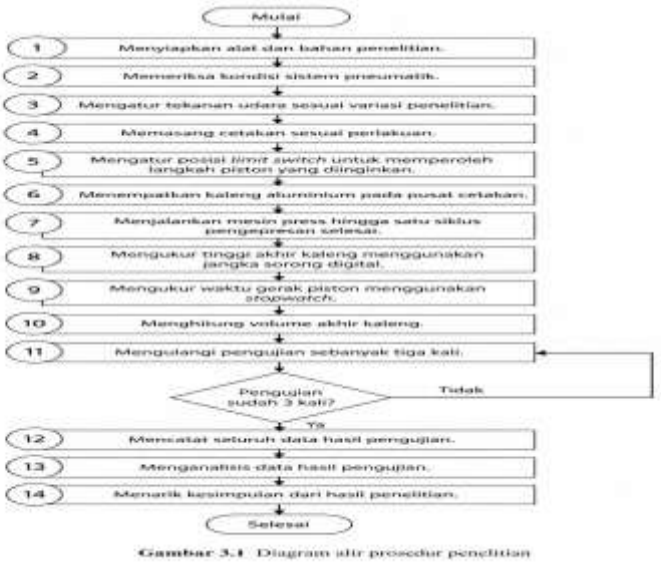
Data collection was performed through direct observation and measurement during the aluminum can pressing process. Each combination of air pressure, mold construction, and piston stroke length was tested according to the experimental design.

The measurement results included:

1. Final height of the can after pressing
2. Piston forward movement time
3. Piston backward movement time
4. Final volume of the can
5. Percentage reduction of can volume

Each test condition was repeated three times to improve data accuracy and reliability.

Data Analysis Technique



Gambar 3.1 Diagram alir prosedur penelitian

Figure 3 Research Flow Diagram

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The experimental data were analyzed using descriptive quantitative analysis. The obtained data were calculated to determine the average value of each treatment condition. The results were presented in tables and graphs to observe the influence of air pressure, mold construction, and piston stroke length on:

1. Final height reduction
2. Pressing time
3. Final volume
4. Volume reduction percentage

The optimum operating condition was determined based on the highest volume reduction and effective pressing time.

Calculation Equations

Pressing Time Efficiency

The pressing time efficiency was calculated by comparing the manual pressing time and the pneumatic machine pressing time.

Equation:

$$C\ (\%) = ((A - B) / A) \times 100\%$$

Where:

C = Pressing time efficiency (%)
A = Manual pressing time (s)
B = Machine pressing time (s)

Given:

A = 78 s
B = 10 s

Calculation:

$$C\ (\%) = ((78 - 10) / 78) \times 100\%$$
$$C\ (\%) = (68 / 78) \times 100\%$$
$$C\ (\%) = 87.18\%$$

Pneumatic Cylinder Force

The force generated by the pneumatic cylinder was calculated using:

Equation:

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$F = A \times P$

$A = \pi \times D^2 / 4$

Where:

F = Cylinder force (N)

A = Piston area (m^2)

P = Working pressure (N/m^2)

D = Piston diameter (m)

Given:

D = 0.08 m

P = 6 bar = 600,000 N/m^2

Calculation:

$A = 3.14 \times (0.08)^2 / 4$

$A = 3.14 \times 0.0064 / 4$

$A = 0.005024\ m^2$

Then:

$F = 0.005024 \times 600{,}000$

$F = 3014.4$ N

Pneumatic Air Consumption

Air consumption per cycle was calculated using:

Equation:

$V = A \times h$

Where:

V = Air consumption per cycle (m^3)

A = Piston area (m^2)

h = Cylinder stroke length (m)

Given:

$A = 0.005024\ m^2$

h = 0.175 m

Calculation:

$V = 0.005024 \times 0.175$

$V = 0.000879\ m^3$/cycle

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Aluminum Can Volume

The initial and final volume of the aluminum can was calculated using:

Equation:

$V = \pi \times d^2 \times h / 4$

Where:

V = Can volume (m^3)

d = Can diameter (m)

h = Can height (m)

Given:

d = 0.05064 m

h = 0.13200 m

Calculation:

$V = 3.14 \times (0.05064)^2 \times 0.13200 / 4$

$V = 3.14 \times 0.002564 \times 0.13200 / 4$

$V = 0.001063 / 4$

$V = 0.000266\ m^3$

Aluminum Can Volume Reduction

The percentage of volume reduction was calculated using:

Equation:

$R (\%) = ((Vi - Vf) / Vi) \times 100\%$

Where:

R = Volume reduction (%)

Vi = Initial volume before pressing (m^3)

Vf = Final volume after pressing (m^3)

Given:

$Vi = 0.000266\ m^3$

$Vf = 0.000017\ m^3$

Calculation:

$R (\%) = ((0.000266 - 0.000017) / 0.000266) \times 100\%$

$R (\%) = (0.000249 / 0.000266) \times 100\%$

$R (\%) = 93.61\%$

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E-ISSN : 2963 4954
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RESULT AND DISCUSSION

Effect of Air Pressure on the End Height of the Can

Nescafe cans using flat molds and 0.010 m piston pitches showed a consistent decrease in final height as air pressure increased. At a pressure of 3.5 bar a final height of 0.02510 m is obtained; at 4.0 bar drops to 0.01985 m; at 4.5 bar to 0.01420 m; and at 5.0 bar reached a low of 0.01005 m from an initial height of 0.13200 m. The same pattern occurs in Lasegar cans with flat molds, namely the final height of 0.02150 m, 0.01675 m, 0.01230 m and 0.00905 m at pressures of 3.5 bar to 5.0 bar, respectively. These two data sets show a consistent monotonous relationship between the increase in air pressure and the decrease in the final height of the can.

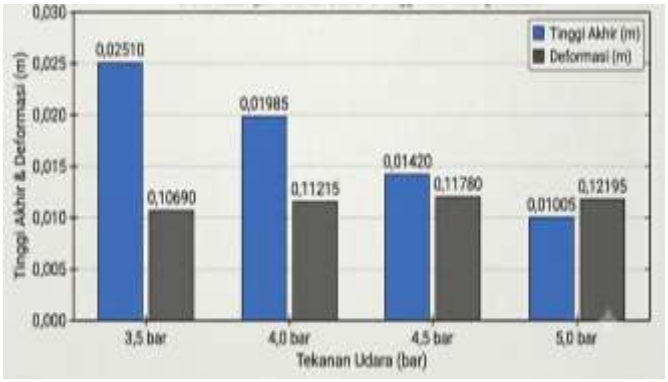


Figure 4 The relationship of air pressure to the final height and deformation of the Nescafe can uses a flat mold and a piston stroke of 0.010 m.

Figure 3.1 shows that the increase in air pressure from 3.5 bar to 5.0 bar causes the final height of the Nescafe can to continue to decrease, while the deformation value increases gradually. This pattern indicates that the compressive energy generated by the pneumatic system is increasingly effective in changing the shape of the can to become denser. The consistent relationship between air pressure and deformation indicates that the pneumatic system is capable of working stably over the entire pressure range tested. These findings show that air pressure is the main factor that determines the success of the aluminum can compaction process.

The decrease in the final height of the Nescafe can from 0.02510 m at a pressure of 3.5 bar to 0.01005 m at a pressure of 5.0 bar showed an increase in compaction effectiveness of 59.96%. In Lasegar cans, the compaction effectiveness achieved was 57.91%, calculated from the final height drop of 0.02150 m to 0.00905 m at the same pressure range. These values prove that air pressure is the most dominant parameter in determining the degree of deformation of cans compared to other treatment variations. Each increase in pressure of 0.5 bar results in a significant decrease in the mean height of the final so that the relationship between pressure and can

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deformation is linear and predictable in this test range.



Figure 5 Effect of air pressure on the final height of the Lasegar can

Figure 5 shows a relatively uniform downward trend in the final height of the Lasegar can with each increase in air pressure. No deviation in the deformation pattern was found during the test process which indicates that the structure of the can is capable of accepting compressive forces stably at all pressure variations. The final drop in height that occurred indicates that the increase in air pressure contributes directly to the effectiveness of compaction. These results reinforce the finding that air pressure is a dominant parameter in controlling the rate of deformation of cans during the pressing process.

This phenomenon can be explained by the pneumatic force equation $F = A \times P$. The cross-sectional area of the cylinder (A) is fixed at 0.005024 m^2 so that the increase in air pressure (P) directly increases the compressive force (F) acting on the piston. The greater compressive force causes the tension on the aluminum can wall to exceed the yield strength of the material more thoroughly, so that the plastic deformation takes place deeper and more permanently (Jiménez et al., 2020). The force accuracy of pneumatic systems is highly dependent on the stability of the air supply pressure so that good pressure regulation results in consistent and repeatable deformation (Benić et al., 2017). The increase in operational pressure in the pneumatic press machine significantly increases the percentage of compaction of the waste can. The results of this study confirm that air pressure is the most critical variable that must be optimized first before considering other variables (Feng et al., 2023).

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Effect of Mold Construction on the End Height of the Can

A comparison between the three types of mold construction shows the measurable difference in performance on each type of can. Nescafe cans with 0.00050 m concave molds and 0.008 m piston stroke produce final heights of 0.02740 m, 0.02215 m, 0.01680 m, and 0.01205 m at pressures of 3.5 bar to 5.0 bar. This value is higher than the result of Nescafe cans on flat molds with a step of 0.010 m which records a final height of 0.01005 m at a pressure of 5.0 bar. The final height difference between a 0.00050 m concave mold and a flat mold at a pressure of 5.0 bar is 0.00200 m which indicates that the difference in mold type has a noticeable influence on the compaction result.



Figure 6 The effect of air pressure on the final height of the Nescafe can uses a concave mold of 0.00050 m and a piston stroke of 0.008 m.

Figure 6 shows that the final height of the Nescafe can continues to decrease as the air pressure increases despite using a concave mold. However, the final height value obtained is still greater than the use of flat molds at the same pressure. This condition shows that the effectiveness of the compaction process is not only affected by the magnitude of the air pressure, but also by the suitability of the mold geometry to the dimensions of the can. In small-diameter cans, a more even distribution of forces in flat molds results in more optimal deformation than the concentration of forces that occur in concave molds.

This difference in performance occurs because the mold construction determines the pattern of compressive force distribution on the surface of the can. Flat molds distribute the force evenly throughout the top cross-section of the can so that the entire wall receives relatively uniform stress and deforms consistently in the axial direction. The concave mold creates a stress

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concentration in the center of the can which theoretically encourages the initial deformation in the direction of faster (Song et al., 2016). However, in small cans such as Nescafe (0.05064 m), this concentration effect is less than optimal because the contact area between the mold protrusion and the surface of the can is too small compared to the total cross-sectional area. This explains why flat molds produce smaller final heights in Nescafe cans than concave molds of 0.00050 m.

Different performance is shown in larger diameter Kratingdaeng cans (0.06541 m) when using 0.00070 m concave molds with 0.010 m piston pitch. The final height of the can obtained was 0.01900 m, 0.01300 m, 0.01900 m, and 0.01400 m at pressures of 3.5 bar, 4.0 bar, 4.5 bar, and 5.0 bar. The data showed an anomaly at a pressure of 4.5 bar, where the final height of the can increased compared to a pressure of 4.0 bar. This condition indicates that increased pressure does not necessarily result in greater axial deformation. This phenomenon is suspected to be related to the occurrence of buckling on the walls of the can during the pressing process (Shveda et al., 2022).

Effect of Piston Stroke on Pressing Results

The variation of the piston stroke indicates an influence on the pressing depth that can be achieved by a pneumatic press machine. In general, a longer piston stroke provides a greater compressive motion space allowing for more optimal can deformation (Yap et al., 2016). In this study, the use of a 0.010 m piston stroke tended to result in a lower can end height compared to a 0.008 m stroke under some test conditions. The findings indicate that the length of the piston stroke contributes to the increased compaction rate of aluminum cans. However, the influence of piston stroke is also affected by the combination of air pressure and mold construction used during the pressing process.A longer piston stroke allows the piston to move further downward during an operating cycle so that the can undergoes deeper compression before the piston returns to its starting position. The greater compression depth provides an opportunity for the aluminum material to undergo more thorough plastic deformation (Benić et al., 2017). On the other hand, the shorter piston stroke limits the compressive distance that can be achieved so that some of the potential for material deformation has not been utilized optimally. In the engine used in this study, the piston stroke length is regulated through the position of the limit switch which functions as a limit to the piston travel. Therefore, the piston stroke setting is one of the important parameters that need to be optimized to obtain maximum compaction results (Drotman et al., 2021).

A longer piston stroke allows the piston to move further downward during a single operating cycle, so that the can undergoes deeper compression before the piston returns to its

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starting position. This greater compression depth provides enough time and distance for the aluminum material to exceed its elasticity limits and enter the plastic deformation zone fully (Benić et al., 2017). At the 0.008 m step, the piston stops early before the entire potential for plastic deformation of the material is reached, so that the final height of the can is greater than the 0.010 m step. The piston stroke adjustment is carried out through the position of the limit switch which functions as a piston travel limiter so that the stroke length can be precisely adjusted without mechanical modifications to the cylinder. A 0.010 m step is recommended for applications that demand the highest level of compaction, while a 0.008 m step can be used for situations that require lighter pressing.

Effect of Treatment Variation on Pressing Time

The measurement of piston movement time shows that the air pressure has an effect on the piston speed and the pressing cycle time. In general, higher pressures result in shorter pressing times because the thrust force on the piston is greater so that the piston moves faster. In contrast, at a lower pressure of 3.5 bar, the movement of the piston becomes slower because the thrust generated is not as large as at high pressure. This condition is consistent with the principle of $F = A \times P$, i.e. the force acting on the piston is proportional to the air pressure, so that the piston with a greater thrust travels the same distance in a shorter time. The overall efficiency of this machine's pressing time reaches 87.18% compared to the manual pressing process which takes an average of 78 seconds, calculated based on the formula $C\% = (A - B)/A \times 100\%$, where B is the machine time of 10 seconds.

The length of the piston stroke also affects the total time of the pressing cycle. A 0.010 m piston stroke requires a longer forward and backward travel time than a 0.008 m stroke because the piston travels a longer distance in each cycle. However, this slightly longer cycle time results in better compaction results, so from a production efficiency standpoint, a 0.010 m step provides a more favorable yield-to-time ratio. (Drotman et al., 2021) states that the speed of the pneumatic actuator is greatly influenced by the supply pressure and the size of the air duct. (Voicu et al., 2022) added that the right solenoid valve control system plays an important role in optimizing the cycle time of the pneumatic press machine.

The impact of pressure on the pressing time also affects the overall productivity of the machine. At a pressure of 5.0 bar, the piston moves faster so that the number of pressing cycles can be performed per unit time is greater than at a pressure of 3.5 bar. This increase in the frequency of cycles directly increases the production capacity of the machine, i.e. the number of

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cans that can be compacted per hour. The use of a 5/2-way 24 VDC solenoid valve in this system allows for a fast and accurate shift in the direction of airflow between the forward and backward movements of the piston, so that pauses between cycles can be minimized. The combination of high pressure and responsive solenoid valve makes this automatic pneumatic press machine have a real productivity advantage over manual and semi-automatic pressing systems.

Analysis of Can Volume Reduction

Analysis of the volume reduction of cans showed significant variation between treatment combinations. The highest volume reduction of 93.4% was achieved in Nescafe cans with flat mold, piston stroke of 0.010 m and pressure of 4.5 bar, calculated from the final height drop of 0.13200 m to 0.01420 m. At a pressure of 5.0 bar with the same treatment, the final height of the Nescafe can drops to 0.01005 m, but the percentage of volume reduction under this condition is slightly lower than that of 4.5 bar. These results indicate the existence of an optimal point at which the addition of pressure no longer provides a proportionate increase in volume reduction, likely because the can has reached its geometric deformation limit at a pressure of 4.5 bar. In Lasegar cans, the volume reduction calculated from a drop in height of 0.10640 m to 0.00905 m at a pressure of 5.0 bar also resulted in a high percentage of compaction, which was around 91.49%.

The difference in volume reduction percentage between types of cans is influenced by three factors, namely the initial dimensions of the cans, the thickness of the material walls and the type of treatment applied. Nescafe cans with an initial height of 0.13200 m have a greater height-to-diameter ratio (slenderness ratio) than Lasegar (0.10640 m) and Kratingdaeng (0.09142 m) so that the absolute height reduction potential is also greater. Cans with higher slimness ratios tend to be more prone to axial deformation when the compressive force acts perpendicular to the axis of the can because the larger wall length provides more collapsible material during pressing. Hopewell et al. (2009) assert that the compaction efficiency of thin metal materials is highly dependent on the ratio of compressive forces to the yield strength of the material and the geometry of the workpiece. This explains why the taller dimensional Nescafe cans resulted in the largest volume reduction despite being the smallest in diameter among the three samples.

The comparison of the results of this study with previous studies strengthens the validity of the findings obtained. (Voicu et al., 2022) reported a volume reduction of about 80% in the pneumatic can crushing machine they developed, while the study achieved 93.4% under optimal conditions. This difference of 13.4% can be explained by the use of an automatic pneumatic system with more optimized pressure, the use of molds that correspond to the dimensions of the

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can, and a piston stroke of 0.010 m that ensures that compression takes place deeper. (Aryanpour & Farzaneh, 2015) It also reports a significant increase in compaction efficiency when air pressure is optimized on its pneumatic press machine. The fact that the highest volume reduction occurs at a pressure of 4.5 bar instead of 5.0 bar indicates the geometric limit of the deformation of the Nescafe can, where at a pressure of 4.5 bar the entire wall of the can is already subjected to the maximum folding that allows this system to work.

Buckling Phenomenon Analysis

Data anomalies were found in the Kratingdaeng can test with a concave mold of 0.00070 m and a piston stroke of 0.010 m. The final height of the can at a pressure of 4.0 bar was recorded at 0.01300 m, but increased to 0.01900 m at a pressure of 4.5 bar. Theoretically, increased pressure should result in greater deformation and lower end height. However, the test results showed the opposite pattern, indicating a different deformation mechanism than other tests. This phenomenon is not found in Nescafe or Lasegar cans which show a consistent decrease in final height as air pressure increases.

The mechanism responsible for this anomaly is the buckling phenomenon, which is a structural instability that occurs when the axial compressive force in a thin element exceeds the critical load so that the element undergoes a sudden and irregular lateral deformation (Song et al., 2016). Kratingdaeng cans have the largest diameter among the three samples (0.06541 m) with a high diameter-to-wall thickness ratio making them more susceptible to buckling than smaller diameter cans. The 0.00070 m concave mold creates a stress concentration in the center of the can that triggers buckling in the lateral direction at a pressure of 4.5 bar, causing the can wall to fold outwards asymmetrically instead of being compressed in the axial direction. As a result, the final height of the can becomes greater than that produced at a pressure of 4.0 bar due to the non-uniform distribution of the material after buckling. This phenomenon is an important finding that needs to be considered in the design of molds for large diameter cans.

Effect of Can Dimensions on Pressing Results

Comparison of results between the three types of cans shows that the initial dimensions of the cans have a significant effect on the deformation pattern and the final height produced. The Nescafe can with a diameter of 0.05064 m and an initial height of 0.13200 m produced the highest volume reduction (93.4%) because it had the largest slenderness ratio among the three samples, namely height divided by diameter of 2.61. The Lasegar can with a diameter of 0.06124

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m and a height of 0.10640 m has a slenderness ratio of 1.74 and produces fairly consistent axial deformation at all pressure variations without anomalies. Kratingdaeng cans with a diameter of 0.06541 m and a height of 0.09142 m have the lowest slenderness ratio (1.40) and show the highest tendency to buckling when using concave molds. This data proves that cans with a higher slenderness ratio tend to be more prone to axial deformation, resulting in greater and more consistent volume reduction.

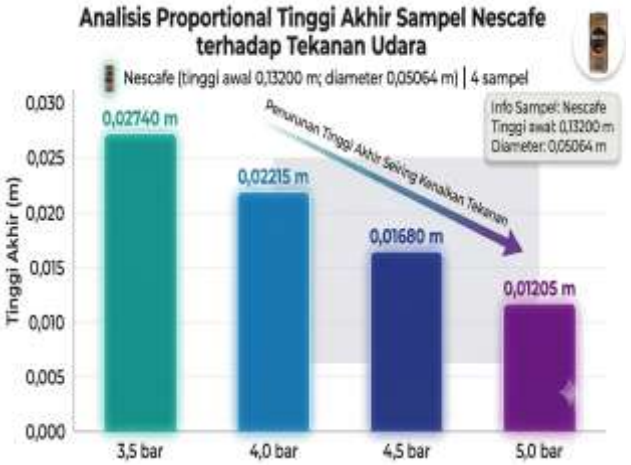


Figure 7 The effect of air pressure on the final height of the Kratingdaeng can used a concave mold of 0.00070 m and a piston stroke of 0.010 m.

Figure 7 shows that the increase in air pressure generally decreases the final height of the Kratingdaeng can. Nonetheless, the resulting deformation response is different from that of Nescafe and Lasegar cans because the larger dimensions of the cans affect the stress distribution pattern during the pressing process. The larger diameter causes the can to be more sensitive to the concentration of forces produced by the concave mold. This condition explains why Kratingdaeng cans have a higher tendency to experience non-uniform deformation and buckling phenomena under certain pressure conditions.

The larger diameter of the can also affects the suitability of the type of mold used. Small diameter (0.05064 m) Nescafe cans work best with flat molds that distribute the force evenly across the entire cross-section. The large diameter Kratingdaeng can (0.06541 m) actually produces the smallest final height (0.00750 m) when using a concave mold of 0.00070 m at a pressure of 5.0 bar because the mold protrusion is able to reach more of the wider cross-sectional center area. However, the use of concave molds on large diameter cans risks triggering buckling if the pressure is not properly optimized. These results confirm that the selection of mold type is inseparable from the dimensional characteristics of the can, and the machine operator needs to

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adjust the mold type based on the diameter of the can to be processed in order to obtain a consistent compaction result and be safe from the risk of buckling.

Best Operating Conditions

Based on the analysis of all test data, the best operating conditions can be reviewed based on two criteria, namely volume reduction and the final height of the can. Based on the volume reduction criteria, the combination of 4.5 bar air pressure, flat mold, and 0.010 m piston stroke is the best condition as it results in the highest volume reduction of 93.4% in Nescafe cans. Meanwhile, based on the can's end height criterion, an air pressure of 5.0 bar resulted in the smallest final height value, which was 0.01005 m in Nescafe cans and 0.00905 m in Lasegar cans. These results show that an increase in pressure of up to 5.0 bar is still able to increase the deformation of the can, but does not necessarily result in a proportionate increase in volume reduction. Therefore, a pressure of 4.5 bar can be considered the most optimal operating condition in terms of compaction effectiveness, while a pressure of 5.0 bar is superior in producing a minimum can end height.

The technical reason why the combination of a pressure of 4.5 bar and a flat mold with a step of 0.010 m gives optimal results on Nescafe cans has to do with the equilibrium point between the applied compressive force and the response of the aluminum material to deformation. At a pressure of 4.5 bar, the compressive force generated is sufficient to push the entire wall of the can beyond the yield limit of the aluminum evenly so that the plastic deformation takes place perfectly along the height of the can. The flat mold ensures a homogeneous force distribution so that no concentration stress triggers unwanted lateral deformation modes. A piston stroke of 0.010 m provides an adequate depth of compression for the material to deform to the minimum geometric limit before the piston returns. The combination of these three factors creates ideal conditions where the aluminum material undergoes maximum plastic deformation with a regular folding pattern, resulting in a volume reduction of 93.4% that exceeds the previous research achievement (Drotman et al., 2021).

The implications of the results of this study on the waste management and aluminum recycling industry are very relevant and can be applied immediately. The volume reduction of more than 93% achieved by this automatic pneumatic press machine means that one can waste transport truck can carry cans equivalent to more than 15 times the volume of uncompacted cans. This reduction in transportation frequency directly reduces fuel costs and carbon emissions from waste transport vehicles, so that these engines contribute to economic efficiency as well as

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environmental sustainability. The time efficiency of 87.18% compared to manual processes also allows one operator to process a much larger number of cans per workday. (Alourani et al., 2025) emphasized that the efficiency of aluminum recycling logistics is a key factor in maximizing the economic value of recycled raw materials and this automatic pneumatic press machine directly contributes to this goal. Further development with PLC control system integration will further improve the consistency and safety of operation of this machine on an industrial scale.

CONCLUSION

This study shows that air pressure, mold construction and piston stroke length affect the performance of automatic pneumatic-based can press machines. Increased air pressure generally results in a greater compressive force so that the end height of the can decreases and the volume reduction increases. Flat molds result in a more even distribution of forces and more consistent deformation, while concave molds are more effective for large-diameter cans but have the potential to give rise to *the phenomenon of buckling*. The use of a 0.010 m piston stroke results in more optimal compaction than a 0.008 m piston stroke. The *buckling phenomenon* was identified in the Kratingdaeng can when using a concave mold of 0.00070 m at a pressure of 4.5 bar. The highest volume reduction of 93.4% was obtained in Nescafe cans with a combination of 4.5 bar pressure of flat mold and a piston stroke of 0.010 m. Overall, the best operating conditions are obtained at a pressure of 5.0 bar with a flat mold and a piston stroke of 0.010 m as it results in optimal compaction without the risk of *buckling*. In addition, the pneumatic press machine developed is able to increase the efficiency of pressing time by 87.18% compared to the manual method.

REFERENCES

Alourani, A., Ashraf, M. U., Aloraini, M., & Angiulli, G. (2025). Smart waste management and classification system using advanced IoT and AI technologies. PeerJ Computer Science, 11. https://doi.org/10.7717/peerj-cs.2777

Aryanpour, G., & Farzaneh, M. (2015). Application of a piston equation to describe die compaction of powders. Powder Technology, 277, 120–125. https://doi.org/10.1016/j.powtec.2015.02.032

Benić, J., Šitum, Ž., & Rajčić, N. (2017). Precise Force Control for Hydraulic and Pneumatic Press System. International Conference Fluid Power. https://doi.org/10.18690/978-961-286-086-8.6

Copyright at authors some right reserved this work is licensed under a Creative Commons Attribution-Share Alike 4.0 International License

Cao, J., Zhu, X., Li, F., & Jin, X. (2019). Modeling and Constrained Optimal Design of an Ultra-Low-Friction Pneumatic Cylinder with Air Bearing. Advances in Mechanical Engineering. https://doi.org/10.1177/1687814019839873

Cuingnet, R., Ladegaillerie, Y., Jossent, J., Maitrot, A., Chedal-Anglay, J., Richard, W., Bernard, M., Woolfenden, J. A., Birot, E., & Chenu, D. (2022). PortiK: A computer vision based solution for real-time automatic solid waste characterization - Application to an aluminium stream. Waste Management, 150, 267–279. https://doi.org/10.1016/j.wasman.2022.05.021

Darmawan. (2021). Design and Construction of a Pneumatic System-Based Beverage Cans Shredding Machine. Cylinder: Scientific Journal of Mechanical Engineering. https://doi.org/10.25170/cylinder.v7i1.4883

Drotman, D., Jadhav, S., Sharp, D., Chan, C., & Tolley, M. (2021). Electronics-free pneumatic circuits for controlling soft-legged robots. Science Robotics, 6. https://doi.org/10.1126/scirobotics.aay2627

Feng, M., Yang, D., Ren, L., Wei, G., & Gu, G. (2023). X-crossing pneumatic artificial muscles. Science Advances, 9. https://doi.org/10.1126/sciadv.adi7133

Jiménez, M., Kurmyshev, E., & Castañeda, C. (2020). Experimental Study of Double-Acting Pneumatic Cylinder. Experimental Techniques, 44, 355–367. https://doi.org/10.1007/s40799-020-00359-8

Maharani, A. D. (2025). Optimizing Air Pressure to Improve the Efficiency of Bottle and Can Waste Pressing on Pneumatic Machines. Journal of Informatics and Applied Electrical Engineering, 13(3). https://doi.org/10.23960/jitet.v13i3S1.7491

Mintaș, O., Simeanu, C., Berchez, O., Marele, D., Osiceanu, A., & Rusu, T. (2023). Impact of Red Sludge Dumps, Originating from Industrial Activity, on the Soil and Underground Water. Water. https://doi.org/10.3390/w15050898

Saputra, M. D. (2021). The design of the press tool control system uses a pneumatic system. ALMICANICS. https://doi.org/10.32832/almikanika.v3i2.5256

Shveda, R. A., Rajappan, A., Yap, T., Liu, Z., Bell, M. D., Jumet, B., Sanchez, V., & Preston, D. (2022). A wearable textile-based pneumatic energy harvesting system for assistive robotics. Science Advances, 8. https://doi.org/10.1126/sciadv.abo2418

Song, W., Liu, S., Pan, H., & Zhu, S. (2016). Investigation on the Design of Hydraulic High-Speed Punching Press with a Large Press Force and a Long Press Stroke. Advances in Mechanical Engineering. https://doi.org/10.1177/1687814016683601

Tejaswini, M., Pathak, P., & Gupta, D. (2022). Sustainable approach for valorization of solid wastes

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as a secondary resource through urban mining. Journal of Environmental Management, 319, 115727. https://doi.org/10.1016/j.jenvman.2022.115727

Tony, M. (2022). Valorization of undervalued aluminum-based waterworks sludge waste for the science of "The 5 Rs' criteria". Applied Water Science, 12, 1–30. https://doi.org/10.1007/s13201-021-01554-7

Voicu, G., Lazea, M., Constantin, G. A., Tudor, P., & Ştefan, E. (2022). ASPECTS REGARDING THE COMPACTION OF CARDBOARD WASTE IN VERTICAL PRESSES WITH DISCONTINUOUS FLOW. INMATEH Agricultural Engineering. https://doi.org/10.35633/inmateh-68-63

Yap, H., Ng, H. Y., & Yeow, C. (2016). High-Force Soft Printable Pneumatics for Soft Robotic Applications. Soft Robotics, 3, 144–158. https://doi.org/10.1089/soro.2016.0030

Zailan, N. A., Azizan, M. M., Hasikin, K., Khairuddin, A. S. M., & Khairuddin, U. (2022). An automated solid waste detection using the optimized YOLO model for riverine management. Frontiers in Public Health, 10. https://doi.org/10.3389/fpubh.2022.907280

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