International Journal of Scientific Research and Engineering Development-– Volume 7 Issue 3, May-June 2024
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Alternative Roofing Accessories: Melting of Aluminum Cans Coated with Zinc from Batteries as Plain Sheets

Wyeth Y. Miranda[1], Michelle G. Doro[2], Karl Angel I. Lim[3], Amiel C. Limpin[4], Precious Nichole E. Magtoto[5],Justine Mae Y. Mangalus[6], Jafet C. Culala[7], Irene R. Roque[8]
[1]Department of Civil Engineering, Don Honorio Ventura State University, Villa de Bacolor, Pampanga
Email: 2020100254@dhvsu.edu.ph

--************************----------------------------------

Abstract:

Recycling is crucial for environmental sustainability, resource conservation, pollution reduction, and economic growth. Since metal waste is one of the recyclable materials in the Philippines and incorporating sustainable materials in construction can significantly reduce pollution, this study aims to create zinc-coated aluminum sheets using aluminum cans and zinc plates from batteries as an alternative roofing material. The researchers opted for metal waste materials to be utilized as roofing accessories, such as gutters and flashing, since aluminum cans are widely used, and zinc plates from used batteries are recyclable and can provide corrosion resistance and durability to aluminum sheets once coated. The project aimed to determine if replacing traditional plain sheets with scrap aluminum that could electroplated with zinc batteries would be feasible and valuable. Quantitative research and experimental research were used in the research design; the materials were gathered from different communities in Pampanga, Philippines, and were readily available. The tensile strength, elongation, and weight of coating of the recycled aluminum sheets were tested using ASTM A370 and ASTM A90. These sheets were ideal for applications requiring strength and endurance without the weight and expense of alternative solutions since they are lightweight, corrosion-resistant, and easily machined.

Keywords **—aluminum sheet, cans, zinc batteries, recycling, roofing, sustainability, alternative, experimental, metal scrap, metal waste, gutter, flashing, corrosion resistance, electroplated, accessory**

--************************----------------------------------

I. INTRODUCTION

Rapid urbanization has given rise to significant environmental concerns. Utilizing sustainable materials in construction can mitigate pollution and ameliorate existing environmental issues. This study explores the incorporation of recycled design elements in the construction sector. There is a growing need for cost-effective, eco-friendly housing projects constructed from locally sourced materials. Such initiatives protect the natural environment, support the economy, and conserve energy [1]. Although the manufacturing sector is anticipated to drive this recovery, elevated interest rates may still have a dampening effect on metal demand.

Metal is one of the most prevalent roofing materials used in the Philippines right now. Metal roofing accessories such as gutters and flashing are increasingly common in a wide range of homes across the nation due to its expanding availability and improved manufacturing techniques. As stated by Nnaji [2] the inclusion of guttering is essential in a roof water harvesting system. It intercepts rainwater runoff and channels it to a downpipe for subsequent storage. This process is critical in safeguarding a home from water damage, as gutters effectively direct rainwater away from the building’s foundation and exterior walls. Effective gutter systems must be durable to withstand weather conditions, affordable and easy to install, efficient in capturing rainwater, resistant to damage, and easy to clean for sustained performance. On the other hand, according to Lutz [3] roof flashing is essential for preventing water damage in roofing systems. It's a thin, corrosion-resistant plain sheet installed in vulnerable areas to redirect water and prevent leaks, protecting against rot, mold, and pest issues.

Moreover, according to Cruz [4], aluminum gutter systems have a typical lifespan of around 20 years. Congruent to this, Ding [5] added that aluminum is widely favored for constructing flashing because of its superior resistance to rust and corrosion. One of the major advantages of aluminum is that it can be easily customized with paint to match the aesthetic of your home. With proper upkeep and maintenance, aluminum flashing can maintain its integrity for over 20 years, making it a highly durable and cost-effective option. As stated by Walker [6], aluminum gutters and flashing can be recycled, which helps conserve resources and reduce environmental impact. To recycle them, take them to a recycling center or scrap yard that accepts aluminum. Before recycling, clean the gutters of debris and contaminants like leaves or paint. Once cleaned, they can be brought to the recycling center. Additionally, you can repurpose aluminum gutters for uses like gardening or water diversion. Recycling aluminum is crucial for resource conservation and waste reduction, contributing to lower energy consumption and greenhouse gas emissions.

Furthermore, as stated by Velasco et al. [7], mishandling solid waste can lead to environmental and public health risks, contaminating the air, soil, and water. In the Philippines, only paper, plastic, iron, metal, glass, and aluminum waste are recyclable. The metal wastes, including aluminum wastes, generated from different fabrication laboratories is 6.63%. Based on the 2023 World Counts, the largest single use of aluminum around the world is aluminum cans, with approximately 180 billion used annually. Aluminum production is notably energy-intensive, surpassing all other metals in energy requirements. It takes more energy to mine and produces aluminum than any other metal. The energy needed to manufacture 4 soda cans is equivalent to filling 1 of these cans with gasoline.

Aluminum (Al) is a versatile and widely used metal known for being lightweight, conductive, and corrosion resistant. Approximately 35% of aluminum is recycled, presenting environmental benefits by saving energy and reducing greenhouse gas emissions. [8]. On the other hand, zinc (Zn) is an abundant metal and serves diverse industrial purposes. Industrial consumption in 2013 totaled around 13 million metric tons, utilized in galvanizing, alloys, chemical production, and die casting.

As per Jamieson [9], zinc sheet metal is highly esteemed due to its enduring nature and ability to withstand corrosion. Initially designed for industrial applications such as roof flashing, cathode protection, and chemical resistance, it has garnered extensive utilization in contemporary construction projects, encompassing roofing, cladding, gutters, and downspouts. Its nonporous characteristics also make it a preferred choice in the commercial sector for applications like countertops and appliances. Metal zinc plating is a widely used industrial process wherein a thin layer of zinc is deposited onto the surface of the primary metal component. Wherein, the advantage of zinc plating is that it is highly rust resistant and slows the corrosion rate up to 30 years. [10]. Moreover, aluminum, renowned for its lower melting point compared to metals like copper, iron, and brass, has a pure form melting point of around 660 degrees Celsius or 1220 degrees Fahrenheit [11]. The ASTM A194 specification [12] cites the melting point of elemental zinc as approximately 780°F (415°C).

According to Ali and Yassen [13], the recycling of aluminum products offers numerous environmental and economic advantages, as it demands less energy and generates fewer greenhouse gas emissions compared to primary extraction processes. Secondary aluminum production involves scrap sorting, processing, cleaning, smelting, refining, alloying, and pouring. During the melting process of aluminum scrap, a layer of oxide forms on the surface of the molten, which must be removed for a high-quality finished product. To remove impurities, flux is used to protect the molten, which results in the formation of aluminum slag. Aluminum slag contains up to 70% free aluminum mixed with an oxide layer. Nevertheless, zinc slag is a waste material generated during zinc manufacturing with potential use in embankment and pavement construction. A research study evaluated the geotechnical characteristics of zinc slag mechanically stabilized with local soils in a 25% to 75% proportion. [14].

Electroplating is a technique or type of galvanizing that involves coating an object with a layer of metal using controlled electrolysis. During the process, an anode (containing the metal for plating) and a cathode (the object to be plated) are submerged in an electrolyte solution and connected to an electrical source. The flow of electricity causes metal ions to transfer from the anode to the cathode, resulting in an even metal coating on the object. Additionally, this study used a specific type of electroplating which is continuous plating. According to Ruff [15], in continuous plating, parts like wires and tubes pass by anodes at a consistent rate. The time length of electroplating can vary greatly depending on several parameters, including the size and intricacy of the object being plated, the desired thickness of the plating, the type of plating solution used, and the current density. Moreover, electroplating tiny objects and thin coatings may take only a few minutes. However, for larger objects or thicker coatings, the procedure may take several hours or even days [16].

Coating aluminum with zinc enhances its resistance to various environmental elements, including moisture, chemicals, and airborne pollutants that lead to deterioration. Additionally, the zinc coating protects against physical harm, such as scratches and impacts. Therefore, combining aluminum and zinc creates a robust material suited for diverse construction applications. It enhances aluminum's appearance and significantly improves its performance and longevity, making it ideal for challenging environments [17].

The escalating global population exerts mounting pressure on natural resources and exacerbates environmental degradation by fueling the demand for raw materials. In the Philippines, the demand for metal scrap was twice the available supply, indicating a ratio of 1:2 between supply and demand. According to Ong [18], the country had 1.65 million mt of scrap demand, up 9.1% year on year. The country's local supply of scrap rose 19.5 % to 2.15 million mt in 2018, while exports hit 500,000 mt. Using waste materials in various industries and applications has emerged as a critical strategy in the pursuit of sustainable development and environmental conservation. Incorporating waste materials into production processes helps mitigate the overall carbon footprint. By diverting materials from landfills, it lessens the demand for raw materials extraction, which often involves energy-intensive and environmentally damaging processes. Additionally, it minimizes the release of greenhouse gasses and pollutants associated with waste decomposition and incineration. The exploration of alternative roofing accessories in plain sheet production has prompted high demand for eco-friendly and sustainable materials.

According to McCullum [19], aluminum is the most common material for gutters and flashing, its thickness is typically gauged in thousandths of an inch, ranging from Gauge 24 (0.51 mm or 0.0201 in) to Gauge 20 (0.81 mm or .0320 in). Lower gauge numbers indicate thinner gutters. The standard in the industry is Gauge 22 (0.64 mm or 0.0253 in) aluminum gutter, suitable for mild to moderate weather conditions. In areas susceptible to extreme weather conditions such as hurricanes or heavy snowfall, a thicker gutter measuring 0.81 mm or 0.0320 inches (gauge 20) may be required. This study focuses on repurposing waste aluminum cans and zinc plates from batteries that can be turned into roofing accessories such as gutters and flashings, which are abundant in urban waste streams. This research aims to determine the potential of these recycled materials as substitutes for traditional plain sheets, with a focus on their mechanical properties, cost-effectiveness, and environmental impact.

II. METHODOLOGY

A. *Research Design*

This study used quantitative and experimental research design since the objectives were answered through the gathered numerical data from the experimentation. According to Sreekumar [20], quantitative research collects and analyzes numerical data to describe variables and seeks to guide the researchers' study by providing formulations of pre-established steps. In addition, experimental research is a scientific approach to comprehending the connections between two or more variables. These groups involve independent and dependent variables that undergo experimental testing to establish a correlation regarding their relationship's nature and intensity, as Blackstad cites [21]. The researchers used quantitative observation to analyze the mechanical properties of recycled materials, and the corrosion resistance of electroplated plain sheets. From that point onwards, the researchers interpreted the gathered data from their experimentation to determine the feasibility of using waste aluminum cans coated with zinc from batteries as raw materials for plain sheets to mitigate metal waste.

B. *Testing of Materials*

The weight of coating and tensile strength test was conducted at DPWH Bureau of Research and Standards located at Quezon City, Metro Manila which engages in research efforts aimed at determining the most suitable standards for implementing projects by the Department of Public Works and Highways (DPWH), collaborating closely with the private sector.

1. *ASTM A370 - Mechanical Testing of Metal Products*

ASTM A370 constitutes a testing standard encompassing mechanical testing definitions and methodologies applicable to a spectrum of metal products, including wrought and cast steels, stainless steels, aluminum, and associated alloys. These criteria encompass evaluations such as tension, bend, hardness, and impact tests [22].Particularly, it serves as a widely acknowledged benchmark for assessing the tensile strength of metals, finding practical utility across industries like construction and automotive manufacturing, where the quality of materials profoundly influences safety standards.

ASTM A370 primarily measures the mechanical properties of metals, with tensile testing being the focus. The key properties typically measured include:

a. Tensile Strength: it represents the utmost force or stress a material can endure prior to fracturing, offering valuable insights into its overall resilience and capacity to withstand tensile forces.

b. Total Elongation: This is the percentage increase in length of a specimen before it breaks during tensile testing. It quantifies the extent to which a material can deform before failing, providing information about its ability to withstand elongation, or stretching.

Computation:

$$Tensile\ Strength, Mpa = \frac{\text{Ultimate Force (N)}}{\text{Area } (mm^2)}$$

2. *ASTM ASTM A90 - Standard Test Method for Weight (Mass) of Coating on Metals with Zinc or Zinc-Alloy Coatings*

ASTM A90 is a test method that offers a standardized approach to assess the weight or mass of coatings on metal particles, particularly those composed of zinc. These coatings serve a crucial role in safeguarding against corrosion. As zinc sacrificially deteriorates over time, its presence provides protection to the underlying material. Therefore, the level of protection directly corresponds to the weight or mass of the zinc coating. Specifications for zinc-coated articles often categorize different classes of coating weights or masses, providing purchasers with options to choose the coating weight that best fits their specific requirements. This ensures that users can select coatings tailored to their needs, optimizing both performance and cost-effectiveness. For metal products, the results are presented as either total coating weight or mass on both sides combined, or coating weight or mass separately for each side, depending on the specified requirements [23].

Computation:

$$\text{Weight of Zinc Coating}, \frac{\text{g}}{\text{m2}} = \frac{\text{a} - \text{b}}{\text{b}}(c)(k)$$

Where:
a – Original weight of specimen, g
b – Weight of stripped specimen, g
c – Thickness of stripped sheet / specimen, mm
k – 7850 = constant

TABLE I
COATING DESIGNATION

Minimum Requirement		
Coating Designation	Triple-Spot Test (g/m^2)	Single-Spot Test (g/m^2)
Z001	no minimum	no minimum
Z90	90	75
Z120	120	90
Z180	180	150
Z275	275	235
Z305	305	275

C. *Data Gathering Procedure*

a. Phase 1. Gather and prepare all the needed materials: The researchers washed and deformed the aluminum cans into smaller pieces to fit into the crucible cup, then removed the outer part of the batteries to reveal the zinc plate. Subsequently, the researchers also prepared the other necessary materials and equipment, such as tongs, gloves, mask, crucible cup, charcoal, blower, DIY melting furnace, and flattening tool, to commence the melting process.

b. Phase 2. Melting of aluminum cans, removing of slag, and getting off heat temperature: Place the crucible cup in the furnace, surrounded by charcoal as the primary heat source. Ignite the charcoal to start the combustion process. Attach a blower to the furnace to increase heat and speed up melting. The burning charcoal transfers heat to the crucible, raising its temperature. Introduce crushed aluminum cans into the crucible once it reaches the desired temperature (typically above 660°C). The intense heat liquefies the aluminum, causing impurities to rise as slag, which is removed. Monitor the crucible temperature throughout the process. Conduct a thorough temperature check upon reaching optimal temperature. The temperature peaked at 1084°C, demonstrating efficient heat transfer and combustion.

c. Phase 3. Shaping and cooling down of the melted metals: Melted aluminum from the crucible was poured into a homemade flattening tool's receptacle. The press plate of the tool was placed atop the melted aluminum to shape it. The aluminum was allowed to cool and solidify slightly. Tongs were utilized to remove the shaped aluminum from the tool's receptacle once it cooled enough to handle. The shaped aluminum was then dipped into water to rapidly cool it down and remove residual heat.

d. Phase 4. Melting of zinc plates from batteries: Zinc plates were obtained from used batteries and cleaned to remove black residue. The crucible was placed back into the melting furnace with charcoal, ignited to generate heat. The blower increased the temperature to zinc's melting point (415°C). Zinc plates were added to the crucible, melted, and any slag removed. Molten zinc temperature was verified (491.2°C). Molten zinc was transferred to a flattening tool's receptacle to cool. After solidifying slightly, the zinc plates were removed with tongs and immersed in water to cool completely.

e. Phase 5. Grinding and sand papering the formed aluminum for smoother and thinner surface: Once melted and flattened, the samples are ground and sanded to remove metal bits and ensure flatness and smoothness. Grinding ensures the samples meet the required shape, texture, thickness, and area for testing purposes.

f. Phase 6. Shaping and cutting aluminum plain sheets into required shape: Researchers used stiff paper to draw and obtain precise dimensions of the sample product. They pasted this template onto plain sheets to guide cutting to the required dimensions. Dog bone-shaped samples for ASTM A370 have 182 mm by 20 mm dimensions, while square samples for ASTM A90 have dimensions of 60 mm by 60 mm. This method ensured accuracy and consistency, enabling standardized testing procedures.

g. Phase 7. Sand papering the samples again to acquire the required thickness (gauge 20, 22, and 24): After shaping and cutting, researchers sandpaper the products to achieve required thicknesses of 20, 22, and 24 gauges for square and dog bone-shaped samples. Sandpapering refines surfaces and ensures uniform thickness, aiding consistent testing and analysis.

h. Phase 8. Clean the samples of aluminum sheet: Clean the samples first using liquid soap and submerge them in a combination of baking soda and vinegar. Then wash the samples with water to ensure that the excess dirt or waste from grinding and sandpapering was removed thoroughly before immersing the samples in the prepared container with solutions.

i. Phase 9. Perform the zinc electroplating on aluminum (1 hour per sample): The researchers gather materials: molded zinc, metal to be plated, vinegar, baking soda, alligator clips, a 12-volt DENEL Motorcycle battery, and a plastic container. They mix vinegar and baking soda in equal amounts to create a solution for electroplating. Alligator clips connect to battery terminals, with the plain sheet attached to the positive terminal and zinc mold to the negative. Samples are submerged for about an hour to ensure thorough zinc coverage. Current flow through the circuit initiates zinc transfer and bonding with the metal, forming a coating.

j. Phase 10. Clean the electroplated aluminum sheet samples by washing them, then place them in a dry towel: After about an hour of submersion, carefully remove the metal from the solution and inspect for even coating. Rinse the metal and place it on a towel to dry, ensuring cleanliness and readiness for further testing.

D. *Data Analysis*

The researchers employed descriptive statistics to describe the numerical data collected during the experiment. This method is the most suitable statistical analysis to be used because it focuses solely on describing the numerical data, aiding in the presentation of results, and drawing conclusions. According to Fraenkel et al. [24], descriptive statistics are utilized when researchers aim to portray numerical data using various techniques, including numerical index or graphical representation.

Additionally, the researchers employed Spearman rank correlation (two-tailed) to ascertain the correlation of thickness (gauge 20, 22, and 24) from tensile strength and elongation. This statistical approach serves as descriptive statistics solely for ensuring data reliability. Since this study only provides a summary of the impact of the independent variable on the dependent variable descriptively, rather than formulating a hypothesis, the Spearman rank correlation is chosen. As outlined by Stats Test [25], this method was utilized to depict the strength and relationship between two variables. Consequently, the generated table would aid in interpreting the data results.

TABLE III
SIZE OF CORRELATION AND ITS INTERPRETATION

Size of Correlation	Interpretation
.90 to 1.00 (-.90 to -1.00)	Very high positive (negative) correlation
.70 to .90 (-.70 to -.90)	High positive (negative) correlation
.50 to .70 (-.50 to -.70)	Moderate positive (negative) correlation
.30 to .50 (-.30 to -.50)	Low positive (negative) correlation
.00 to .30 (.00 to -.30)	negligible correlation

Credits: Parvez Ahammad

Furthermore, the researchers employed IBM SPSS software for conducting the statistical test. According to Tech Target Contributor [26], IBM SPSS (Statistical Package for the Social Sciences) is modeling software utilized for testing and processing data, specifically for ensuring data reliability and analysis purposes.

III. RESULTS AND DISCUSSIONS

A. *Tensile Strength Test*

The entire document should be in Times New Roman or Times font. Type 3 fonts must not be used. Other font types may be used if needed for special purposes.

Recommended font sizes are shown in Table 1.Understanding the tensile strength of aluminum plain sheets is essential as it indicates the maximum stress the material can endure before fracturing under tension. A higher tensile strength signifies superior resistance to stretching or pulling forces, rendering the plain sheet more robust and capable of bearing heavier loads without failure. Conversely, lower tensile strength implies a weaker material prone to deformation or failure when subjected to ension. To determine tensile strength, the aluminum plain sheet is subjected to tension until it reaches its breaking point, and the applied force is measured.

A. *Total Elongation*

Title must be in 24 pt Regular font. Author name must be in 11 pt Regular font. Author affiliation must be in 10 pt ItalicIt is the extent to which a material can stretch or deform before breaking under tension. Greater elongation signifies increased ductility and flexibility, enabling the aluminum plain sheet to undergo more deformation before breaking. On the other hand, lower elongation indicates a more brittle characteristic, making the material susceptible to fracturing under stress.

TABLE IIIII
TENSILE STRENGTH AND FINAL LENGTH ELONGATION

Specimen		Thickness (mm)	Width (mm)	Ultimate Force (N)	Tensile Strength (MPa)	Ave. TS (MPa)	Final Length Elonga-tion (%)	Ave. FLE (%)
Gauge 20	1	0.82	12.5	778.25	75.927	87.335	57+2.636	57+2.864
	2	0.81	12.5	660.75	65.259		57+2.394	
	3	0.83	12.5	1253.5	120.819		57+3.561	
Gauge 22	1	0.64	12.5	1064.25	133.031	189.628	57+3.127	57+3.338
	2	0.69	12.5	1808	209.623		57+3.111	
	3	0.61	12.5	1725	226.230		57+3.777	
Gauge 24	1	0.55	12.5	2153	313.164	355.435	57+3.807	57+5.582
	2	0.48	12.5	2307	384.500		57+7.786	
	3	0.5	12.5	2304	368.640		57+5.152	

The table above indicates the data acquired for tensile strength and final elongation of the three (3) specimens (gauge 20, 22, and 24) using ASTM A370.

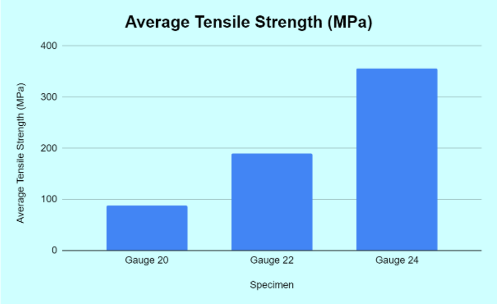


Fig. 1. Average Tensile Strength

Figure 1 shows the accumulated data with regards to the tensile strength exhibited by the material as per the different gauges utilized in this study. Particularly, the highest average tensile strength was acquired by gauge 24 which is 355.435 MPa. On the other hand, gauge 20 achieved the lowest tensile strength of 87.335 MPa. These results show that as the thickness of the material decreases the tensile strength increases making the two variables indirectly proportional, thus for further explanation data analysis of Spearman rank correlation (two-tailed) will be conducted by the researchers.

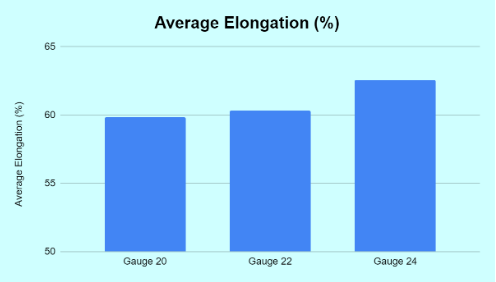
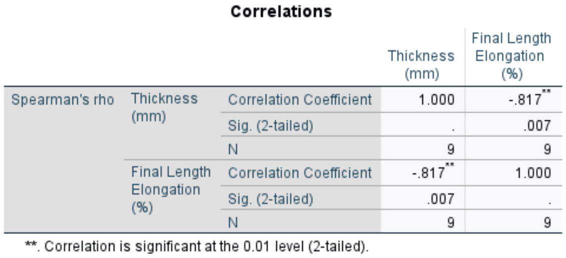


Fig. 2. Average Total Elongation

Figure 2 presents that in terms of the final length elongation that the material has performed, it can be proof that as the material decreases in terms of its thickness the elongation of the material has significantly increased. Particularly, gauge 20 acquired the lowest average elongation, which is 57+2.864 %, while gauge 24 has the highest elongation of 57+5.582 %.



Correlations

			Thickness (mm)	Final Length Elongation (%)
Spearman's rho	Thickness (mm)	Correlation Coefficient	1.000	-.817**
		Sig. (2-tailed)	.	.007
		N	9	9
	Final Length Elongation (%)	Correlation Coefficient	-.817**	1.000
		Sig. (2-tailed)	.007	.
		N	9	9

**. Correlation is significant at the 0.01 level (2-tailed).

Fig. 3. Correlation Between Thickness and Tensile Strength

Figure 3 illustrates that the two variables have a significant relationship of 0.001. The Spearman rho value is -.917; thus, the variables have a very high negative correlation. This means that they are inversely proportional to one another. As the thickness increases, the tensile strength decreases, and vice versa.

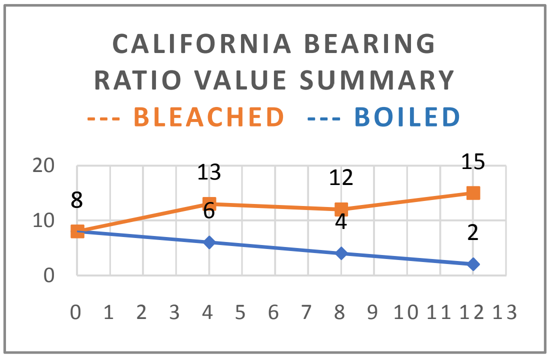


Fig. 4. Correlation Between Thickness and Total Elongation

Figure 4 shows that the two variables have a significant relationship of 0.007. Particularly, the spearman rho value is -.817; therefore, a high negative correlation exists between the variables, this means that they are inversely proportional to one another, as the thickness increases, the elongation decreases, and vice versa.

B. Weight of Coating

The quantity of coating on an aluminum plain sheet can be assessed through its weight of coating. Generally, a higher weight of coating suggests a thicker and more resilient coating, offering better defense against environmental factors like moisture and oxidation that are common causes of corrosion, while a lower weight of coating may imply a thinner coating, potentially providing less protection against corrosion. Measuring the mass of the coated aluminum plain sheet and comparing it to its mass when stripped can determine the weight of coating.

TABLE IVV
WEIGHT OF COATING

Specimen	Weight of coating (g/m²)	Triple Spot (g/m²)	Single Spot, (g/m²)	Unit Weight of Sheet, (kg/m²)	Thick-ness Coating Desig-nation
Gauge 20 (R) (C) (L)	153.7778 100.3319 108.4530	120.8542	100.3319	6.4781	Z120
Gauge 22 (R) (C) (L)	118.2872 75.6145 79.2761	90.3277	75.6145	5.124	Z90

Gauge 22 (R) (C) (L)	106.6149 75.3035 90.7319	90.8834	75.3035	4.1294	Z90

The table shows the accumulated data about the ASTM A90 test, which measures the weight (mass) of zinc coating on aluminum sheets by immersing it for a minute in a solution of 50% Hydrochloric Acid (HCL) and 50% water (H20). This examination aids in verifying the quality and uniformity of the coating applied to aluminum sheets. The data presented in the table is tabulated by different gauge sizes of aluminum sheets (20, 22, 24), with three samples labeled R, C, and L for each gauge size. These samples represent different conditions or positions on the sheets, such as right, center, and left. For each sample, the table includes measurements such as the original weight of the sheet, the weight after the ASTM A90 test, the thickness of the sheet, and other properties related to the coating.

Furthermore, regarding the average weight of the triple spot coating on one side of aluminum sheet samples R, C, L: gauge 20 exhibited approximately 120.8542 g/m², gauge 22 recorded a 90.3277 g/m², and gauge 24 recorded a 90.8834 g/m². As for the single spot coating weight covering both sides of aluminum sheet samples, which is the lower value from the three samples (R, C, L), Gauge 20 showed 100.3319 g/m², while Gauges 22 and 24 both recorded 75.6145 g/m² and 75.3035 g/m² respectively. Consequently, all gauges (20, 22, 24) have adhered to the criteria specified in the Table of Specification, signifying the specific coating designation. Therefore, gauge 20, with its higher coating amounts of around 120 g/m² and 100 g/m², is labeled as Z120 (G40), while gauges 22 and 24, with slightly lower coating amounts of about 90 g/m² and 75 g/m², are both labeled as Z90(G30) Where Z120 is in SI Units, and G40 is in Inch-Pound Unit, indicate that the weight of zinc on both sides per square meter is 120 grams, which also signifies in Z90.

As a result, gauge 20, labeled as Z120, can effectively block moisture from reaching the aluminum sheet, enhancing its resistance to corrosion [27]. Such extends the expected lifespan due to the thicker coating providing better protection, limiting the exposure of the metal to the environment. On the contrary, gauges 22 and 24, labeled as Z90, represent the lowest average coating weight, offering only moderate protection. Sheets with this designation are more prone to rusting because of their thinner coating. Thus, the thickness of the coating directly impacts the corrosion resistance of the aluminum sheet, with thicker coatings providing more excellent protection against corrosion while thinner coatings offer less protection.

Additionally, in terms of the weight of aluminum sheets measured in kilograms per square meter (kg/m²), gauge 20 stands out as the heaviest with a measurement of 6.4781 kg/m². In contrast, gauge 24 appears to be the lightest among the three, having a value of 4.1290 kg/m². This observation suggests that as the thickness of the sheets increases, their weight also tends to increase, following a direct proportionality.

C. Cost Analysis

In conducting cost analysis, it is imperative to prioritize raw material expenses and labor costs, as they substantially influence overall expenditure and profitability. These costs were often variable and could be controlled more easily than fixed costs, allowing for optimization and improved cost competitiveness. Furthermore, the researchers computed the basic needed for cost production to determine the production cost per unit of recycled aluminum sheets, including the direct material cost, labor cost, and equipment and tools cost, excluded the cost of logistics, fabrication, transportation, and testing of the materials from the calculation, since the study was focused on experimentation.

TABLE V
PRODUCTION COST PER UNIT SHEET (8 FT X 4 FT X 1 MM)

Label	Item	Unit	Quantity per 25 Sheet	Prices
Material Cost	Aluminum Cans	pcs	7 500	₱ 6 250
	Battery	pcs	2 500	₱ 2 500

	Baking Soda	g	500	₱ 40
	Datu Puti Vinegar	li	5	₱ 200
	Distilled Water	li	5	₱ 150
Labor Cost per material (20% of material cost)				₱ 1 828
Equipment Cost	Metal Furnace			₱ 8 000
	Flattening Tool			₱ 1 000
ESTIMATED COST PER SHEET $\left(\frac{\text{Material + Labor + Equipment Cost}}{25\ sheets}\right)$				₱ 798.72

The table above presents the production cost per unit of the produced plain sheet of the developed recycled aluminum plain sheet of this study and in comparison, to the conventional aluminum plain sheet that is readily available on the market, generated from the internet as a source of literature. The researchers need a 3:1 ratio of primary materials, aluminum cans and zinc plates from batteries, to produce a quantity of aluminum sheets. On the other hand, the average amount of aluminum sheets produced in mass production is 25 pieces (8ft by 4ft with 1 mm thick) per day [28]. In which the cost per unit sheets that are readily available in the market sizing 8ft by 4ft with 1 mm thickness from the different suppliers are: Matibay Scaffolding Supply is Php 1, 130, Heiwa Industrial Sales cost Php 2, 300, Takezo Industrial Supply costing Php 2 400, Metal Rise Enterprise costing a Php 1 550, and Millenium Specialty Alloys Ltd. (from online shop) costing a Php 2, 000, averaging an estimated cost of per material of Php 1876.

Thus, recycled aluminum sheets exhibited a Php 798.72 estimated material cost, which is relatively lower than the readily available materials since the direct raw materials are metal waste and can be bought cheaply. For this cost analysis table, the computed cost analysis is the basic calculation for the material cost and labor cost considering only the dimensions of 8ft by 4ft with a thickness of 1 mm for producing aluminum sheets with equipment calculated.

The material cost includes 7 500 pieces of aluminum cans equivalent to Php 6, 250 (Php 250 every 300 cans), 100 pieces of battery amounting to Php 2, 500 (1 peso each), baking soda (Php 40), vinegar (Php 200), distilled water (Php 150) for the materials used for the electroplating process. The labor cost, determined to be 20% of the total material cost as referenced by Sullivan [29], has been computed to amount to Php 1,828. This percentage is selected based on the Labor Market Analyzer's insights, which indicate that the labor cost percentage varies depending on the depth of the cost analysis, ranging from 20% to 40%. A labor cost equivalent to 20% of the total material cost signifies expenses directly associated with labor, excluding additional costs like administrative overhead and tools and equipment. Given the researchers' focus solely on the direct costs of manufacturing an 8ft by 4ft by 1 mm aluminum sheet, the 20% figure is deemed appropriate.

Moreover, the researchers reported costs for equipment and tools: Php 8,000 for a DIY melting furnace and Php 1, 000 for flattening tools. To compute the total production cost per unit, add the material cost (Php 9 140), labor cost (Php 1, 828), and equipment cost (Php 9, 000) divided by the quantity of produced aluminum sheets, which is 25 pieces. Therefore, the production cost per unit of recycled aluminum sheets is Php 798.72, making it more cost-saving and economical than the existing one.

IV. CONCLUSIONS

The researchers successfully produced a plain sheet using metal waste such as aluminum cans and used batteries with any brand which are readily available from households as discarded materials. Over several weeks of experimentation, samples of various dimensions were obtained with a thickness of gauge 20 (0.81mm), gauge 22 (0.64 mm), and gauge 24 (0.51 mm) for both dog-boned shapes measuring 182 mm to 20 mm and squared samples measuring 60 mm by 60 mm. Several tests, such as ASTM A90 for coating mass and ASTM A370 for tensile strength, were conducted to assess whether the recycled aluminum plain sheets meet the required standards set by ASTM for plain sheets.

In terms of tensile strength which corresponds to the material's ability to withstand pulling forces without breaking; the average tensile strength of Gauge 20, Gauge 22, and Gauge 24 was 87.335 MPa, 189.628 MPa, and 335.435 respectively. Relatively, gauge 24 has the highest average tensile strength while gauge 20 has the lowest. Thus, this means that gauge 24 which has a thickness of 0.51 mm achieved the highest tensile strength of 335.435 MPa, it indicates that the as the thickness of the material decreases the tensile strength increases. Additionally, all the samples of recycled aluminum sheet conform to the standard tensile strength of aluminum sheet which ranges from 70-700 MPa based on the study of Deng [30]. Moreover, the minimum requirement of 42 MPa for the tensile strength test in gutter mechanical properties is crucial for gutter system design, manufacturing, and performance assessment. It ensures gutters have sufficient strength to endure environmental pressures, uphold structural integrity, and effectively manage rainwater runoff. This requirement enhances the durability, reliability, and safety of building drainage systems [31]. This inverse relationship between material thickness and tensile strength has significant implications for material selection in various applications. It suggests that careful consideration of material thickness may be necessary based on the specific strength requirements of a given application. Thinner materials may be preferred when high tensile strength is crucial, while thicker materials could be suitable when properties such as flexibility outweigh tensile strength.

As regards the final elongation at breaks that occurs when the applied stress exceeds the stretch limit of the material. It represents the deformation or increase in length experienced by the material and is often expressed as a percentage of the original length. Based on the given data, the average total elongation of Gauge 20, Gauge 22, and Gauge 24 was 57+2.864 %, 57+3.338 %, and 57+5.582 % respectively. As per acquired, gauge 24, the thinner option, demonstrated the highest elongation at 57+5.582 %, while gauge 20, the thicker one, showed the lowest elongation at 57+2.864 %. This highlights the inverse relationship between material thickness and elongation, indicating that thinner materials generally possess higher elongation values. Moreover, the material acquired a 1.71 % as the minimum elongation of the material came from the 3 % of the initial length which is the 57%. Therefore, all samples of recycled aluminum sheets meet the required minimum standards of less than 3% of the initial length of the material [32].

In both analyses, the table reveals a significant relationship between the variables, with rho values of 0.001 and 0.007 respectively, leading to the rejection of the null hypothesis. Specifically, the Spearman's rho values of -0.917 indicate a very high negative correlation between thickness and tensile strength. Congruent to this, the Spearman's rho values of -0.817 indicate a high negative correlation between thickness and elongation. This implies that as the thickness increases, the tensile strength and elongation decreases, and vice versa.

The findings on the mass of coating to the material specify that all gauges of aluminum sheet samples (20, 22, 24) meet the requirements and criteria for coating designation. Gauge 20 shows the highest coating weight, labeled as coating designation of Z120, indicating a thicker coating compared to gauges 22 and 24, which are labeled as coating designation of Z90 [33]. Thicker coatings, like those on gauge 20 mean it provides better protection against corrosion, thus, it extends the lifespan of the aluminum sheet. Whilst gauges 22 and 24, with thinner coatings offer only moderate protection. This means it makes it more susceptible to rusting, reducing its longevity.

Furthermore, the study observes a direct relationship between sheet thickness and weight, with thicker sheets like gauge 20 being heavier. This relationship is intuitive, as thicker materials typically weigh more. Where it emphasizes the critical role of coating thickness in determining the corrosion resistance and overall performance of aluminum sheets. According to Sen and Tareq [34], thicker coatings provide better protection, enhancing the durability and lifespan of the sheets, while thinner coatings offer lower protection leading to premature deterioration of material.

The study compares the production cost per unit of recycled aluminum plain sheets developed in the research and the costs of available plain sheets measuring 8ft x 4 ft x 1 mm that are readily available in the market. The findings showed that the recycled aluminum sheets had a lower cost per sheet, primarily because the primary raw material, metal waste, could also be obtained at a lower cost. Additional expenses for the electroplating process, such as baking soda, vinegar, and distilled water, along with labor costs, were also relatively low, totaling Php 798.72 per sheet. In contrast, readily available to the market (conventional) had a higher average cost per sheet, amounting to an average of Php 1,876. This higher cost is due to various factors, encompassing the extraction and refinement of raw materials, manufacturing operations, distribution logistics, and marketing expenditures inherent in conventional production methodologies.

Overall, the findings suggest that utilizing recycled materials in producing aluminum sheets can lead to significant cost savings. This highlights the economic feasibility and attractiveness of adopting sustainable manufacturing practices, contributing to environmental conservation and economic efficiency.

REFERENCES

[1] P. V. Patel and A. Patel, “Use of sustainable green materials in construction of green buildings for sustainable development,” IOP Conference Series, vol. 785, no. 1, p. 012009, Jun. 2021, doi: 10.1088/1755-1315/785/1/012009.

[2] C. C. Nnaji, I. T. Tenebe, and P. C. Emenike, “Optimal sizing of roof gutters and hopper for rainwater harvesting,” Environmental Monitoring and Assessment, vol. 191, no. 6, May 2019, doi: 10.1007/s10661-019-7434-z.

[3] A. Lutz, “What is roof flashing?” Architectural Digest, Feb. 06, 2024. https://www.architecturaldigest.com/reviews/roofing/what-is-roof-flashing

[4] E. Cruz, “Guide to gutters: How long do gutters last & How can I increase gutter lifespan?” Ned Stevens, Aug. 24, 2022. https://nedstevensli.com/how-long-do-gutters-last/#:~:text=Overall%2C%20aluminum%20gutter%20systems%20have,shorter)%20than%20their%20average%20lifespan.

[5] RP. Ding, “Roof flashing: Understanding this essential roof component,” Sunvek Roofing, Jul. 14, 2023. https://sunvek.com/blog/roof-flashing/#:~:text=Aluminum,shape%20for%20over%2020%20years

[6] J. Walker, “Recycling and repurposing Aluminum Gutters: A guide,” Can You Throw It Away, Jan. 11, 2023. https://canyouthrowitaway.com/can-you-recycle-aluminum-gutters/ M. Shell. (2002) IEEEtran homepage on CTAN. [Online]. Available: http://www.ctan.org/tex-archive/macros/latex/contrib/supported/IEEEtran/

[7] *L. C. P. Velasco, M. J. Burden, M. J. Satiniaman, R. B. Uy, L. V. Pueblos, and R. Gimena, “Preliminary assessment of solid waste in Philippine Fabrication Laboratories,” AIMS Environmental Science, vol. 8, no. 3, pp. 255–267, Jan. 2021, doi: 10.3934/environsci.2021017.*“PDCA12-70 data sheet,” Opto Speed SA, Mezzovico, Switzerland.

[8] S. Capuzzi and G. Timelli, “Preparation and Melting of Scrap in Aluminum Recycling: A Review,” Metals, vol. 8, no. 4, p. 249, Apr. 2018, doi: https://doi.org/10.3390/met8040249.

[9] M. Jamieson, “Everything You Need to Know About Zinc Sheet Metal,” Heather & Little, Jun. 20, 2022. https://heatherandlittle.com/blog/everything-you-need-to-know-about-zinc-sheet-metal/#:~:text=Today%2C%20zinc%20sheet%20metal%20is

[10] *“What are the benefits of zinc plating? - Professional plating,” Professional Plating, Jul. 24, 2020. https://www.proplating.com/benefits-zinc-plating/.*

[11] "Melting Point of Aluminum," Thyssenkrupp Materials. 2024. https://www.thyssenkrupp-materials.co.uk/melting-point-of-aluminium.

[12] Fine Metals Corp., "Zinc Plate," https://finemetalscorp.com/product/zinc-plate/.

[13] M. M. Ali and R. S. Yassen, “Recovery of Aluminum from Industrial Waste (Slag) by Melting and Electrorefining Processes,” Al-Khwarizmi Engineering Journal/ Al- Khwarizmi Engineering Journal, vol. 14, no. 3, pp. 81–91, Sep. 2018, doi: 10.22153/kej.2018.03.002.

[14] IRJMETS - International Research Journal of Modernization in Engineering Technology and Science, “IRJMETS,” IRJMETS International Research Journal of Modernization in Engineering Technology and Science. https://www.irjmets.com/uploadedfiles/paper//issue_9_september_2023/44739/final/fin_irjmets1695282758.pdf.

[15] B. Ruff MA, “How to Electroplate Household Metals (with Pictures) - wiki How,” wiki How, Apr. 11, 2024. https://www.wikihow.com/Electroplate-Household-Metals

[16] *Libre texts. (2023, August 29). Electroplating. Chemistry Libre Texts. https://chem.libretexts.org/Bookshelves/Analytical_Chemistry/Supplemental_Modules_(Analytical_Chemistry)/Electrochemistry/Electrolytic_Cells/Electroplating*S. Capuzzi and G. Timelli, “Preparation and Melting of Scrap in Aluminum Recycling: A Review,” Metals, vol. 8, no. 4, p. 249, Apr. 2018, doi: https://doi.org/10.3390/met8040249.

[17] Wpmaster, “Can Aluminum be Galvanized and Where Can I Buy Them,” Aaluminum, Nov. 18, 2023. https://aaluminum.com/blog/can-aluminum-be-galvanized/#:~:text=Coating%20aluminum%20with%20zinc%20not,water%20pipes%2C%20and%20similar%20constructions.

[18] *C. C. M. Ong, “Analysis: ASEAN’s 2019/2020 scrap needs to grow amid steel glut concerns,” S&P Global Commodity Insights, Oct. 11, 2019. [Online]. Available: https://www.spglobal.com/commodityinsights/pt/market-insights/latest-news/metals/101119-analysis-aseans-2019-2020-scrap-needs-to-grow-amid-steel-glut-concerns*

[19] K. McCullum, “Standard Gutter Sizes | Modernize,” Modernize, Feb. 16, 2023. https://modernize.com/gutters/sizes

[20] *D. Sreekumar, “What is Quantitative Research? Definition, Methods, Types, and Examples | Researcher.Life,” Oct. 19, 2023. https://researcher.life/blog/article/what-is-quantitative-research-types-and-examples/#:~:text=Quantitative%20research%20is%20the%20process,generalizing%20results%20to%20wider%20populations.*

[21] O. Blakstad, “Experimental Research - a guide to scientific experiments.” https://explorable.com/experimental-research

[22] ADMET, Inc., “How to perform ASTM A370 Mechanical Testing of Steel Products - ADMET,” ADMET, Apr. 28, 2021. https://www.admet.com/testing-applications/testing-standards/astm-a370-mechanical-testing-of-steel-products/#:~:text=ASTM%20A370%20%7C%20Metals%20%7C%20Tension%20Testing,%2C%20hardness%2C%20and%20impact%20test

s.E. Cruz, “Guide to gutters: How long do gutters last & How can I increase gutter lifespan?” Ned Stevens, Aug. 24, 2022. https://nedstevensli.com/how-long-do-gutters-last/#:~:text=Overall%2C%20aluminum%20gutter%20systems%20have,shorter)%20than%20their%20average%20lifespan.

[23] “Standard Test Method for Weight [Mass] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings.” https://www.astm.org/a0090_a0090m-13.html

[24] J. Fraenkel, N. Wallen, and H. Hyun, How to Design and Evaluate Research in Education, 8th ed. 2012. [Online]. Available: https://saochhengpheng.wordpress.com/wp-content/uploads/2017/03/jack_fraenkel_norman_wallen_helen_hyun-how_to_design_and_evaluate_research_in_education_8th_edition_-mcgraw-hill_humanities_social_sciences_languages2011.pdf

[25] *“Spearman’s RHO - StatsTest.com,” StatsTest.com, Apr. 07, 2020. https://www.statstest.com/spearmans-rho/*

[26] T. Contributor, “SPSS (Statistical Package for the Social Sciences),” What Is, Oct. 11, 2018. https://www.techtarget.com/whatis/definition/SPSS-Statistical-Package-for-the-Social-Sciences

[27] *“Standard specification for steel sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-DIP process.” https://www.astm.org/a0653_a0653m-09.html*

[28] “Project Report of Galvanized Iron Roofing Sheet Purpose of the Document,” Samadhan Nurturing Dreams - Innovative Solutions, Oct. 12, 2020. https://www.kviconline.gov.in/pmegp/pmegpweb/docs/commonprojectprofile/GALVENIZEDIRONROOFINGSHEETS.pdf

[29] A. Sullivan, “What Percentage of Construction Costs Is Labor?” The Future of Bookkeeping, Jul. 05, 2023. https://www.botkeeper.com/blog/construction-labor-cost-percent

[30] Y. Deng, “Galvanized Aluminum vs. Galvanized Steel: Understanding the Advantages & Applications for Your Projects,” *Proleantech | Custom Parts On-Demand Manufacturing*, Mar. 05, 2024. https://proleantech.com/galvanized-aluminum-vs-galvanized-steel/

[31] “Cornered rain gutter and fittings - Technical Informations / Physical and Mechanic Properties | Fırat Plastic.” Available: https://www.firat.com/en-us/rain-gutters/cornered-rain-gutter-and-fittings/technical-informations-physical-and-mechanic-properties

[32] “The mechanical properties of aluminum | Italpres.” https://www.italpres.com/aluminium-die-casting-news/mechanical-properties-aluminum#:~:text=The%20elongation%20of%20aluminum,elongation%20rate%20of%20about%208%25\

[33] “Standard specification for steel sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy- Coated (Galvannealed) by the Hot-DIP process.” https://www.astm.org/a0653_a0653m-09.html

[34] A. Sen and S. H. Tareq, “Effect of Zinc Coating Thickness on the Corrosion Behavior of Galvanized Corrugated Iron Sheets in Fresh Water, Brine (3.5%NaCl) and Sea Water Environments,” International Journal of Science and Engineering Investigations, vol. 5, no. 54, Jul. 2016, [Online]. Available: https://www.researchgate.net/publication/318205848_Effect_of_Zinc_Coating_Thickness_on_the_Corrosion_Behavior_of_Galvanized_Corrugated_Iron_Sheets_in_Fresh_Water_Brine_35NaCl_and_Sea_Water_Environments