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Research Article

Design Sustainability for Battery Packaging to Increase Customer Satisfaction

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An automotive battery, also known as a car battery, is a device that provides electrical energy to start a vehicle's engine; it uses chemical reactions between lead (Pb) and other chemicals to generate electricity. The automotive industry has been receiving positive feedback from consumers, and the industry has been striving to improve the quality of its product packaging, which protects the battery and facilitates its distribution. The research aims to increase customer satisfaction in the automotive industry by creating better battery packaging design. The research employs a range of methods to achieve this goal, including conducting an initial survey with customers who have purchased and used car batteries to identify problems, 3D computer-aided design (CAD) to create design packaging development, life-cycle assessment (LCA) to measure the environmental impact of various materials and contains sustainability analysis, and finite element analysis (FEA) simulation of the packaging corrugated paper using SolidWorks 2021 software, and lastly, a customer feedback survey is conducted to assess the attributes of packaging development. The design criteria prioritize green materials, ergonomics, durability, reliability, and ease of use. In conclusion, the study recommends the use of corrugated paper for battery packaging in the automotive industry. The corrugated paper has proven to be an ecofriendly and sustainable material that provides excellent protection for the battery while also being easy to handle and use.

1. Introduction

The automotive industry faces challenges in finding ways to reduce gas emissions and energy consumption and improve the recyclability of components, while also maintaining cost competitiveness. In 2014, Aly et al. [1] studied the optimization of the design and material selection of sandwich panels with the aim of reducing weight and costs. In 2023, Lenort et al. [2] studied determining the factors that influence the priority of goals for sustainable development in the automotive industry. Sustainable supply chain management has also been carried out in the automotive industry for the implementation of a circular economy which can affect financial performance [3]. Furthermore, the development of hybrid electric vehicles (HEV) has carried out research and development regarding the field and difference of temperature within a battery package and simulated with computational fluid dynamics (CFD) [4]. Learning about other designs has also been carried out to present the packaging design for electric vehicle (EV) batteries with a multiphysics optimization framework [5]. Nevertheless, the environmental impact of manufacturing EVs is greater than that of the internal combustion engine (ICE) vehicles. In the previous literature, an assessment of the environmental performance was conducted that was impacted by battery size and charging electricity source, using LCA scenario with three varied scenarios [6].

Currently, car batteries have a broad market and are received positively by consumers. With positive feedback from consumers, the automotive industry is trying to increase the quality of its product. As shown in the car battery sales data at one of automotive industries in Indonesia during the period 2018–2021, car battery sales experienced a fluctuating decline (see Figure 1). According to Statistics Indonesia [7], the escalation in the number of motor vehicles and the type of passenger cars, from 2018 to 2020, has increased significantly,

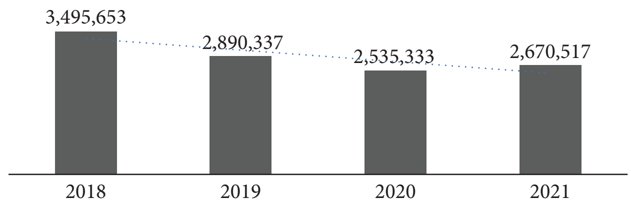


Figure 1: Car battery sales data of an automotive industry in Indonesia.

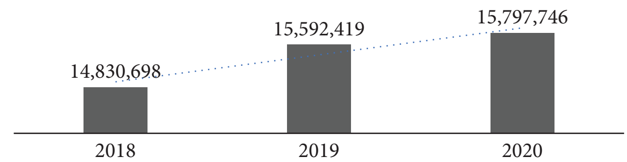


Figure 2: The demand for batteries in Indonesia [7].

as shown in Figure 2. However, the demand for batteries in Indonesia from 2018 to 2020 has increased; this is contrary to the sale of car batteries at an automotive industry in Indonesia. Through these data, it could be a source to increase customer satisfaction by enhancing the product quality, with a focus on improving the packaging.

Product packaging, specifically carton packaging, is a crucial component of a product. It serves as both a protective barrier and a promotional tool, making it equally important as the product itself. Customers consider packaging as a significant factor when making purchasing decisions.

This research focuses on the scope limitations, which are 3D CAD design, sustainability simulation for making new sustainable packaging, and FEA simulation of the packaging corrugated paper using the SolidWorks 2021 software. The objective of this research was to design car battery packaging (corrugated paper) using 3D CAD based on the wishes and needs of the customer (customer requirements). This research applies sustainability analysis and finite element analysis for the development of car battery packaging in the manufacturing industry using SolidWorks 2021.

The rest of the paper is organized as follows. In Section 2, the literature review relevant to the research problem and solution are explored. In Section 3, the research methods and materials analysis were delivered. In Section 4, the results and discussion of the proposed recommendations for the battery industry are presented. Finally, in Section 5, the conclusion and recommendation are delivered.

2. Literature Review

2.1. Stanford Design Thinking. Stanford design thinking is a framework that will be adopted in the process of product design and development. By following its stages, we can gain insights into what needs to be done during the product development phase. The "Stanford model of design thinking," adopted from Plattner, Meinel, and dan Weinberg, is developed by the Hasso Plattner Institute of Design at Stanford University (2009) into a "design thinking framework" (see Figure 3).

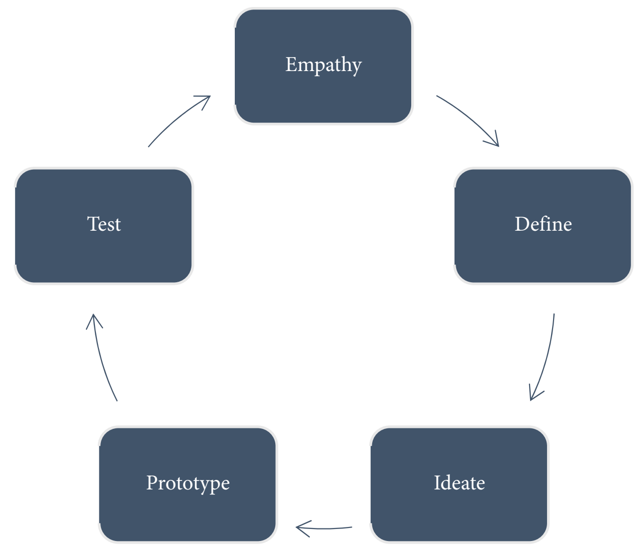


Figure 3: Stanford model of design thinking [8].

There are 5 stages of the Stanford model of design thinking which are as follows [8]:

(i) Empathy: Study the problem from the user's point of view, eliminate self-bias, and correctly identify the problem. In the first stage, the designer collects data about users through observation and interviews.

(ii) Define: According to the information obtained in the previous stage, the designer builds a point of view based on the user's wishes and defines the problem. At this stage, the designer considers the user and the context as well as the underlying problem.

(iii) Ideate: Designers construct ideas and possible solutions to defined problems. At the third stage, it is important that during idea generation, the designer is allowed to provide ideas without restrictions so that they can think of new and innovative creative ideas that go beyond traditional or existing methods.

(iv) Prototype: Often referred to as simulations or specimens, that can be employed in the upcoming stage. In the fourth stage, there is at least one idea that has been selected from all the ideas generated.

(v) Test: Testing is done to put the prototype steps to use and to gather feedback after the implementation of the prototype. In the fifth stage, feedback is very important because there is no indication of the effectiveness of the prototype in solving problems.

2.2. New Product Development. New product development (NPD) is a crucial aspect of product innovation management and involves aligning organizational objectives with the broader societal need to make the product more efficient, cost-effective, and competitive. The purpose of prototyping in NPD is a key in the development process, where designers utilize various methods to investigate specific design challenges and opportunities. Hence, it is broadly recognized that advancements in the prototype phase lead to product improvements [9].

The product design process encompasses various techniques for development and evaluation methods, including sketching, prototyping, and physical testing. With advancements in CAD tools and growing demand for quicker and more efficient product design, virtual modeling and prototyping is becoming increasingly prevalent. Industries such as automotive and construction sectors have long utilized virtual prototyping. In spite of that, some industries such as corrugated board packaging still struggle to adopt it due to the challenges of material management and defined CAD environment for virtual testing. Despite the field of design or engineering, prototyping plays a crucial purpose in the product design. During this stage, the performance and requirements of the product are established [10].

2.3. Design Sustainable. Sustainability analysis is employed in the manufacturing industry to evaluate the environmental consequences of a product. It takes into account all stages of the product's lifecycle that can potentially impact the environment, including the selection of raw materials, production processes, distribution, usage, recycling, final disposal, and other related factors. Typically, this analysis involves assessing the extent to which these stages influence environmental impact categories such as pollution and greenhouse effects [11].

As shown in Figure 4, it represents the systematic approach of the sustainable design and the stages in the sustainability analysis using SolidWorks 2021. There are several inputs, including the following:

(1) Material selection
(2) Manufacturing process
(3) Manufacturing region
(4) Transportation and use

These inputs are then processed through the following steps:

(1) Finding similar materials
(2) Setting a baseline
(3) Modifying the design
(4) Modifying input

This process then results in the following outputs:

(1) Carbon emissions
(2) Total energy consumed
(3) Air pollution
(4) Water pollution

3. Materials and Methods

This study aimed to design and create packaging for automotive batteries. A survey of customer requirements was conducted, and the packaging was developed following the product design and development methods. The CAD modeling and the sustainability analysis were done using SolidWorks 2021 software. The car battery carton box packaging at one of the automotive industry currently is shown in Figure 4.

3.1. Materials' Preparation. Material selection is crucial to consider that the material achieves the purpose and scope of development. Table 1 shows four different types of corrugated paperboard.

Based on the customer requirements obtained from the questionnaire, the selection of the most suitable type of corrugated paperboard according to the customer is B-flute with a thickness of 2.1 mm, with single wall. The size chosen is $243 \times 134 \times 245$ mm according to the size of the battery because the size chosen is the type that is most widely needed, with a corrugated paperboard box weighing 145 g.

3.2. Design and Development Phase. From the previous stage, it has been determined that the results of the development and packaging design of a car battery box have the following requirements (based on the technical characteristics through the collection of customer initial survey data):

(i) Packaging thickness 3.2 mm (B-flute)
(ii) Red packaging color
(iii) Packaging size $243 \times 134 \times 245$ mm
(iv) Packaging reusable
(v) Packaging lightweight 145 g
(vi) Packaging material: corrugated paperboard box
(vii) Additional information about waste management
(viii) Additional handle

Packaging box CAD modeling was assisted with SolidWorks 2021 tools, as shown in Figure 5. Meanwhile, the new packaging design is shown in Figure 6. Figure 7 shows the drawing of a new design of the automotive battery packaging corrugated paper.

3.3. Sustainability Analysis. Through CAD modeling, a sustainability simulation of the packaging corrugated paperboard box was carried out using the SolidWorks 2021 software. The sustainability analysis can evaluate the impact of the environment on the lifecycle of the product. In this study, the comparison of various materials for the existing packaging design has been presented to ensure sustainable solutions for products and environmental impact. The characteristics of the default packing material are as follows:

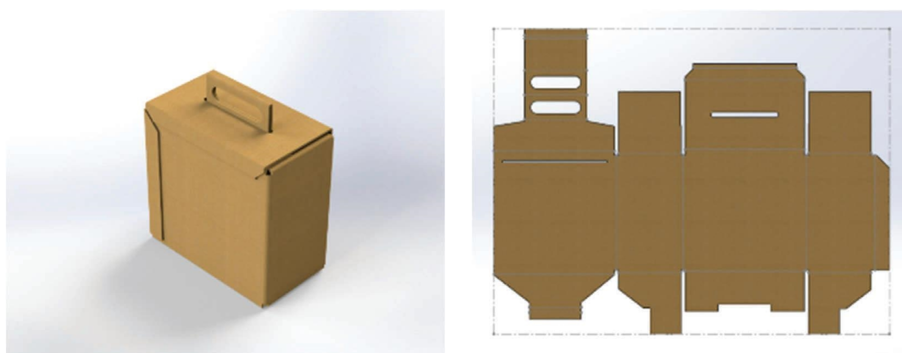
Materials: corrugated paper
Material class: other nonmetals
Density: 156 kg/m^3

Following are various approaches to sustainability and life cycle assessment concepts.

3.3.1. Defining Material. In the first stage, the corrugated paper was selected as the material for further analysis. The purpose of this phase is to compare alternative materials with a baseline of environmental or cost impact in order to select a new material that results in a more favorable impact. The results of the comparison are shown in Table 2.

(a) (b) (c)

Figure 4: Current automotive battery packaging box: (a) angle view, (b) side view, and (c) front view.



(a) (b)

Figure 5: CAD modeling of packaging corrugated paperboard box: (a) 3D model and (b) die-cut.

Table 1: Characteristics of the types of corrugated paperboard [13].

Characteristics	B-flute	Unit
Strength	Low	—
Thickness	2.1	Millimeter (mm)
Wall	Single	—

The reason for comparing materials with corrugated board boxes and corrugated paper is because these materials have advantages, including safety, ease of handling, protection of the product, and communication of information to consumers. The corrugated paper had some excellent benefits, i.e., sustainability and cost [14]. The use of paper as a packaging material has several advantages directly or passively. The cardboard surfaces of paper packaging materials can be utilized to provide information that is displayed on products or product containers, plates, cartons, and trays. The difference between paper packaging and paperboard packaging comes from the raw materials used. Typically, paperboard packaging is coated with various polymers including low-density polyethylene, high-density polyethylene, polypropylene, and polyester to enhance its properties such as increased strength and resistance to chemicals [15].

In consequence, the implementation of paper and paperboard materials has several limitations, such as low quality against water resistance, chemicals, and less strength. So, the selection of other materials such as pine is carried out as a comparative test of the environmental impact or the sustainability analysis because the pine material is considered to be stronger and more resistant to water and chemicals. As shown in previous research, material selection and design for beverage packaging such as wine compares the material to be selected, between pine/wood and corrugated paper [16].

3.3.2. Manufacturing Place and Process. The second stage consists of the following steps:

(i) Setting the **region** of manufacture, in this case, the researcher used Asia

(ii) Filling in the value of the length of time and the part built last is **built to last**

(iii) Setting a manufacturing **process** and inputting the total amount of electricity consumed, total amount of natural gas consumed, and scrap rate or rate of the waste

(iv) Choosing the **paint options**, in this case, just choose no paint

(v) Input information on the **transportation** and distance traveled from the manufacturing location to the consumer location

3.3.3. Environmental Impact. This dashboard offers real-time information regarding the environmental footprint of the design. The environmental impact is calculated using the CML method, which includes the following indicators:

(a) (b) (c)

Figure 6: New packaging design: (a) side view, (b) angle view, and (c) front view.

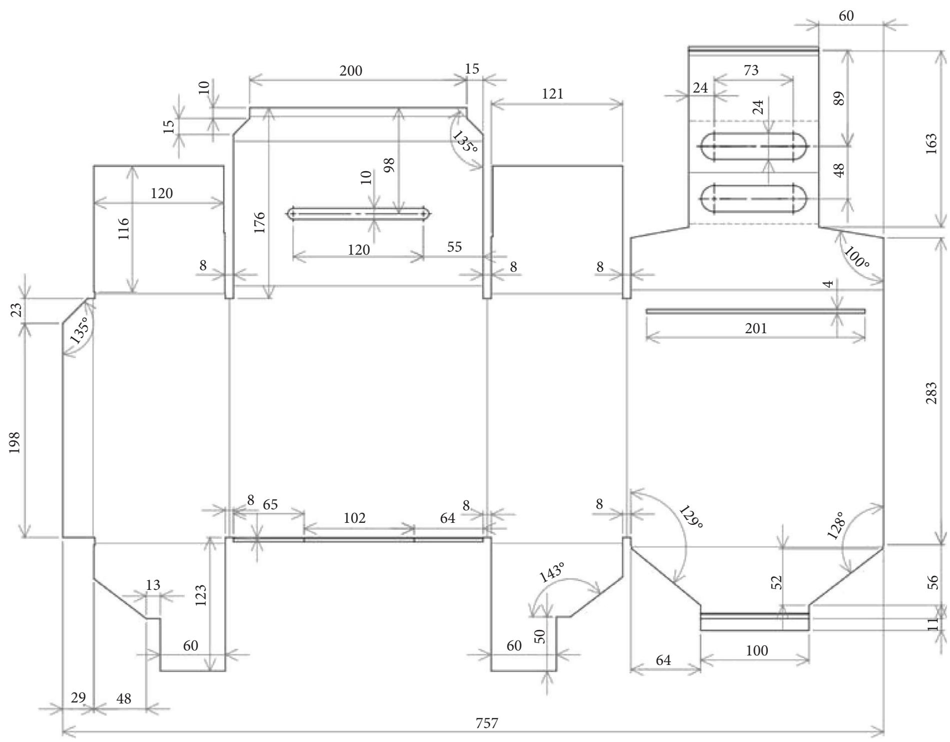


Figure 7: Packaging corrugated paperboard dimensions (units in mm).

(i) Carbon footprint: measurement of greenhouse gas (GHG) emissions caused by the packaging, and it includes carbon dioxide and equivalent, as well as other gases such as carbon monoxide and methane

(ii) Energy consumption: measurement of how much energy the manufacturing process consumes in producing packaging

(iii) Water eutrophication: the process of water pollution due to the emergence of excessive nutrients into aquatic ecosystems

(iv) Air acidification: emission of acids, including sulfur dioxide and nitrous oxide, which contribute to the formation of acid rain

4. Results and Discussion

4.1. Sustainability Analysis. Table 3 presents a comparison of the outcomes of the characteristics of each material in the sustainability report generated from SolidWorks software. It is found that the corrugated paper material has a lighter weight compared to the other two materials, with the weight of corrugated paper being 159.39 g.

Table 4 shows the environmental impact of the three compared materials. The corrugated paper material has the least negative impact on the environment, which is shown in the sustainability report that corrugated paper only produces 1.1 kg CO_2 in its production, 11 MJ in total energy consumed, 0.0069 kg SO_2 in producing air pollutants and

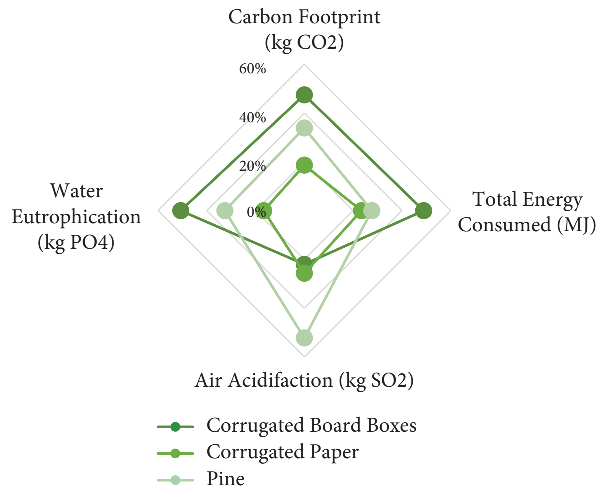


Figure 8: Environmental impact of packaging with the corrugated paper material.

Table 2: Criteria for comparing materials.

Materials	Criteria	
	Material class	Density (kg/m^3)
Corrugated board boxes	Packaging materials	500
Corrugated paper	Other non-metals	156
Pine	Woods	340

acidification varies, and 0.00092 kg PO_4 in causing pollution to aquatic ecosystems.

A clearer comparison can be seen in Figure 8, as corrugated paper is more profitable in its sustainability analysis. Therefore, corrugated paper was chosen as the material to be used in the design and development of car battery products.

4.2. Finite Element Analysis (FEA). In this part, we carried out an FEA simulation on the selection of materials that have been compared, namely, corrugated paper. Table 5 shows the properties experienced by the material, corrugated paper.

There were simulation parameters that had been carried out on the material using the SolidWorks tool, as shown in Table 6. The total load experienced by the packaging was 10.5 kg equal to 102 Newton according to the weight of the most common car battery produced with the type that has been selected (see Figure 9), and the thickness selected uses 3.2 mm.

4.2.1. von Mises' Stress. The von Mises' stress on existing packaging corrugated board boxes at load 102 N is obtained and shown in Figure 10.

The static stress is analysed by selecting the existing packaging corrugated board boxes' material. The maximum stress obtained is $1.634e+07\ \mathrm{N/m^2}$ and the minimum stress obtained is $3.356e+03\ \mathrm{N/m^2}$.

4.2.2. Resultant Displacement. The resultant displacement on existing packaging corrugated board boxes at load 102 N is obtained and shown in Figure 11.

The displacement at load 102 N obtained by selecting the existing packaging corrugated board boxes material is $1.238e+04$ mm. The simulation results show that the bottom cover is not damaged so it is still safe from the given load.

4.2.3. Equivalent Strain. The highest strain concentration is in the holder part of the packaging because it acts as a load support, with a maximum strain and a minimum strain magnitude of $2.965e+00$ and $3.661e-04$, as shown in Figure 12.

4.3. Experiment. After going through the design and development stages of the packaging, an experiment was then carried out by first creating a prototype of the automotive packaging, as shown in Figure 13.

4.3.1. Drop and Lift Test Procedure. At this stage, we continued to carry out experiments on the packaging by lifting and dropping the packaging. The weight of the battery load was the total force for the packaging which is equal to 8.13 kg. Table 7 shows the results of the drop and lift test of corrugated paper packaging.

All conditions from the drop and lift test are shown in Figure 14, as seen from the handle, the side, and the lid.

4.4. Customer Feedback Survey. Manufacturers validate the designed product in the market by following the steps, such as prototype testing (experiment) and customer feedback

Table 3: Comparison of material characteristics from sustainability reports.

Criteria	Materials		
	Corrugated board boxes	Corrugated paper	Pine
Weight	510.86 g	159.39 g	347.38 g
Surface area	$6.55E+5\ \text{mm}^2$	$6.55E+5\ \text{mm}^2$	$6.55E+5\ \text{mm}^2$

Table 4: Comparison of material environmental impact from sustainability reports.

Materials	Environmental impact		
	Corrugated board boxes	Corrugated paper	Pine
Carbon footprint (kg CO_2)	2.8	1.1	2
Total energy consumed (MJ)	23	11	13
Air acidification (kg SO_2)	$5.90E-03$	$6.90E-03$	0.014
Water eutrophication (kg PO_4)	$2.80E-03$	$9.20E-04$	$1.80E-03$

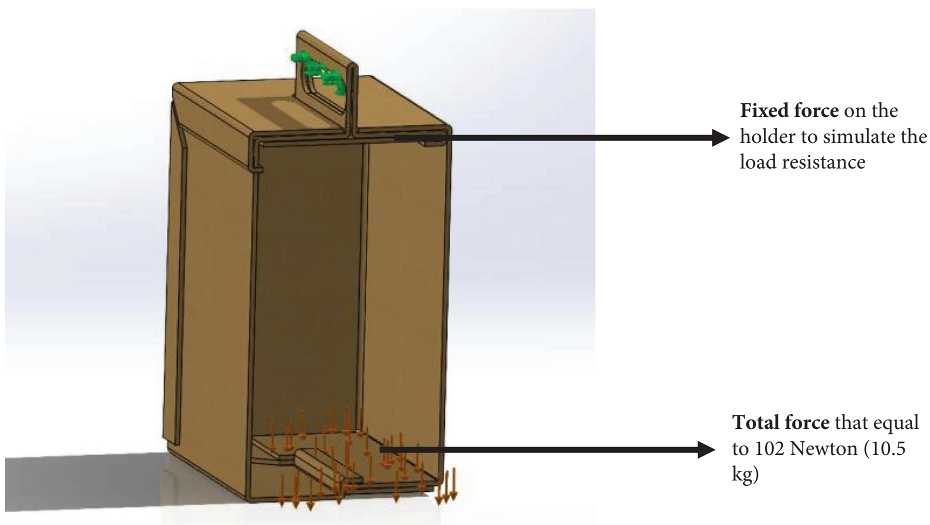


Figure 9: Force scheme.

Table 5: Material properties.

Name	Corrugated paper
Model type	Linear elastic isotropic
Default failure criterion	Max von Mises' stress
Yield strength	$582.000\ \text{N/m}^2$
Tensile strength	$117.400\ \text{N/m}^2$
Elastic modulus	$3.381e+06\ \text{N/m}^2$
Poisson's ratio	0.34
Mass density	$156\ \text{kg/m}^3$
Shear modulus	$3.189e+08\ \text{N/m}^2$

Table 6: Simulation parameters.

Parameters	Description
Material	Corrugated paper board
Material thickness	3.2 mm
Total force	10.5 kg (102 Newton)
Geometric interaction	Bonding interface

survey. In increasing customer satisfaction, data collection was carried out in the form of a customer feedback survey to find out how much product packaging has developed and can satisfy consumers. The survey was conducted on 19 respondents (the sample size is large enough to provide a representative representation of the target population), the survey was conducted at the end of 2022 using Microsoft Forms, and it was designed as a closed survey, and the respondents are consumers who had bought and experienced car battery packs first-hand. However, in general, the automotive industry targets individuals and businesses that are interested in purchasing vehicles or related products and services.

Based on Figures 15 and 16, 19 respondents felt that the developed automotive battery packaging was awesome, attractive, very easy to use, very suitable for automotive batteries, an excellent product, and a good idea, and were willing to purchase it. Then, in Figure 17 consumer judgments on the latest packaging design attributes are shown. The assessment utilizes a Likert scale, where "excellent" is rated 5 points, "good" is rated 4 points, "fair" is rated 3 points, "poor" is rated 2 points, and "very poor" is rated 1 point.

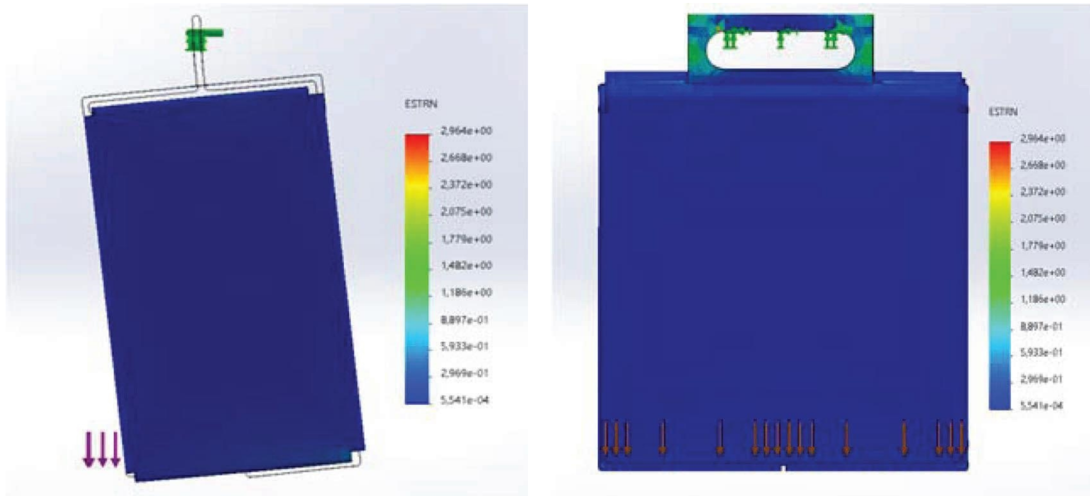


Figure 10: von Mises' stress at load 102 N.

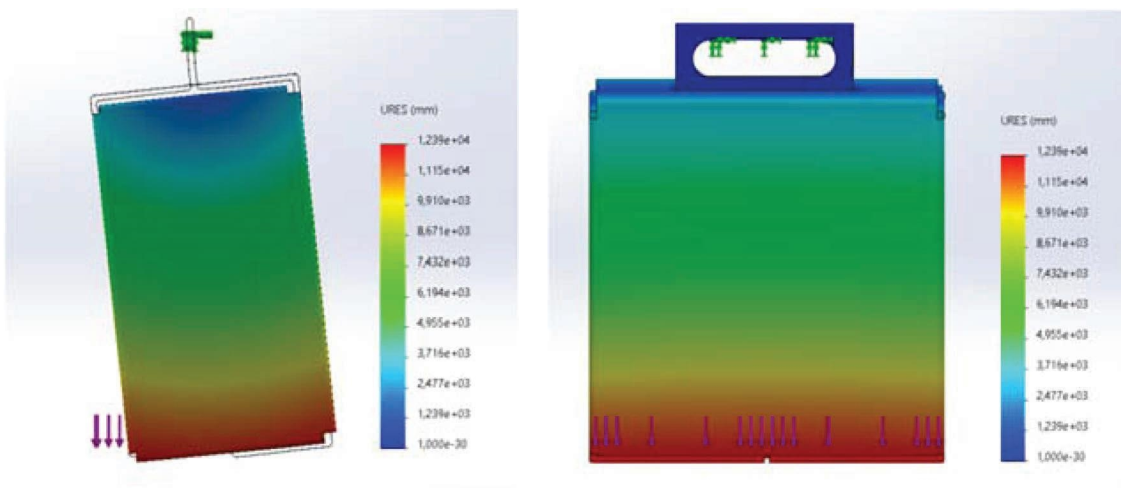


Figure 11: Resultant displacement at load 102 N.

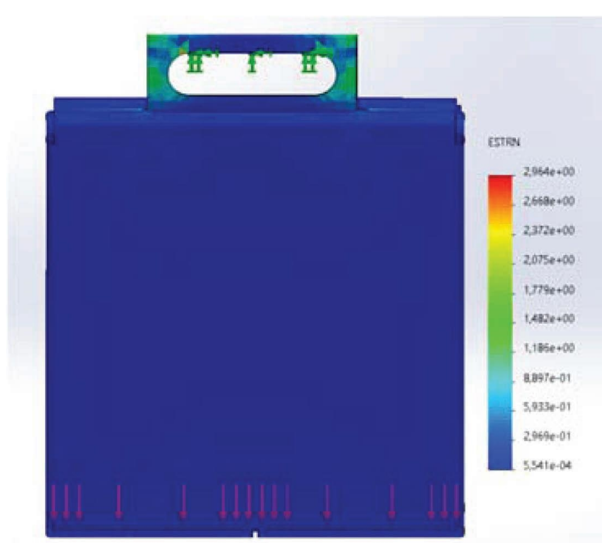
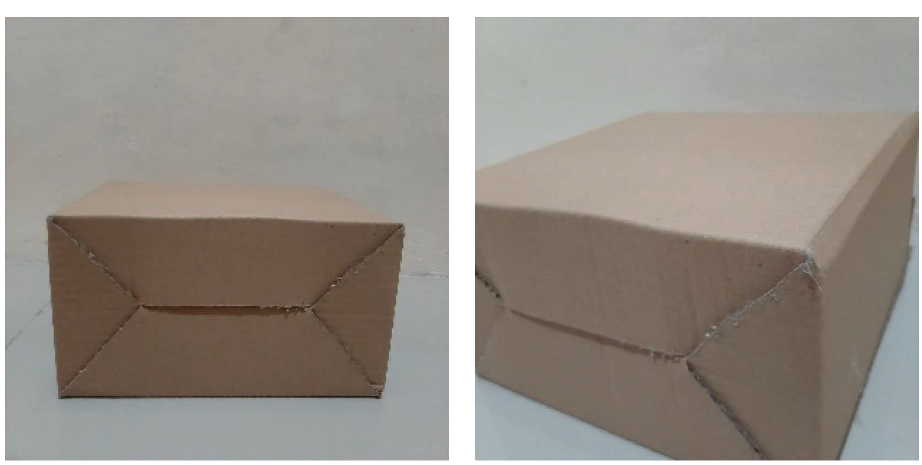


Figure 12: Equivalent strain at load 102 N.

(a)

(b)

Figure 13: Prototype of the new packaging design: (a) die-cut and (b) form as an automotive packaging.



(a) (b)

Figure 14: Continued.

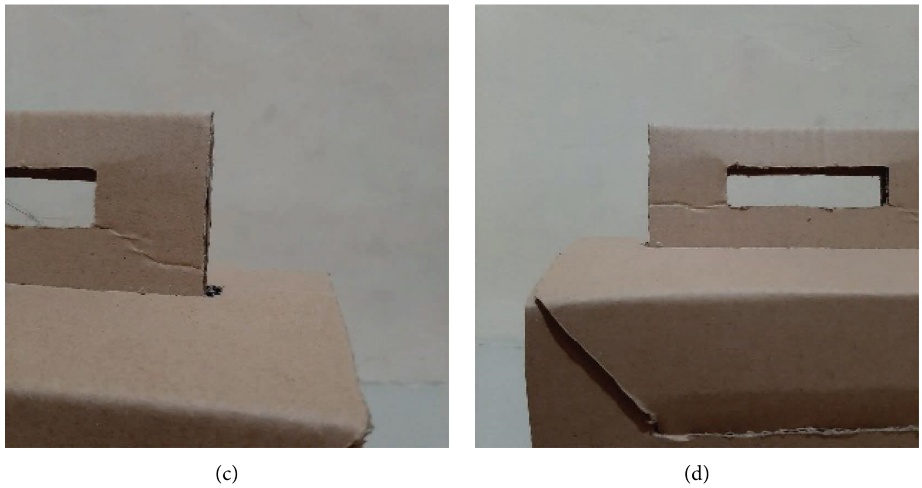


Figure 14: Circumstances of body box from the drop and lift test: (a) bottom part, (b) angle part, (c) right handle part, and (d) left handle part.

Table 7: Drop test visual defect findings.

Attributes	Condition
Damage	No
Suitable for use	Yes
Circumstances of box handle	Good
Circumstances of box surface	Good
Easy to lift (ergonomic)	Yes
Easy to drop (ergonomic)	Yes

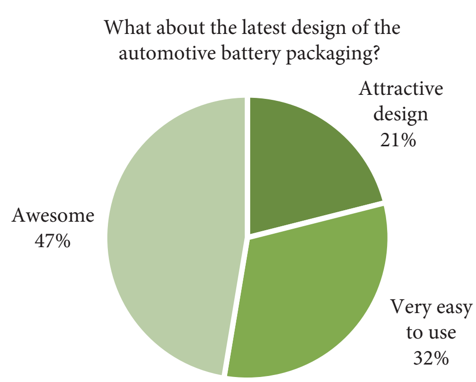


Figure 15: Consumer opinion about the latest design.

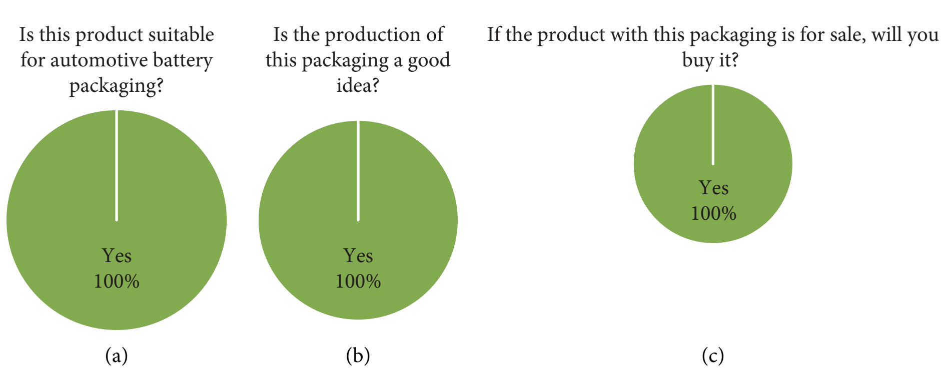


Figure 16: Consumer opinion about the packaging: (a) the suitability for automotive batteries, (b) the idea for production, and (c) the consumer's desire to purchase.

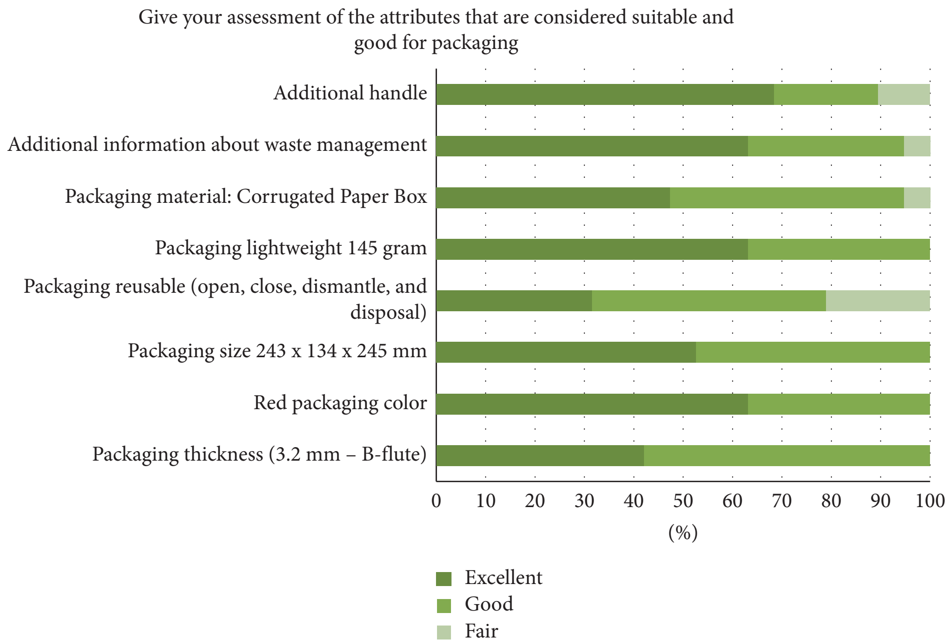


Figure 17: Consumer assessment of the attributes of the latest packaging design.

Table 8: The result of the consumer's assessment of each attribute.

Attributes	Total rating
Packaging thickness (3.2 mm—B-flute)	4.4211
Red packaging color	4.6316
Packaging size 243 × 134 × 245 mm	4.5263
Packaging reusable (open, close, dismantle, and disposal)	4.1053
Packaging lightweight 145 Gram	4.6316
Packaging material: corrugated paper box	4.4211
Additional information about waste management	4.5789
Additional handle	4.5789

From Table 8, it can be seen that the attribute that has the lowest value is packaging reusable (ease of use of packaging, including open-close, dismantle, and disposal methods on the packaging), with a value of 4.1053. It can be said that there needs to be more improvement in this attribute in packaging development. Meanwhile, the highest scores were obtained by the red packaging color and packaging lightweight attributes with values of 4.6316, meaning that the developed packaging on these attributes was very good and suitable for the packaging of automotive battery products.

5. Conclusions

From the results, it can be concluded that the new design is superior to the existing design because it has several attributes that make the design improve, which are packaging thickness, red packaging color, packaging size, packaging reusable, packaging lightweight, packaging material corrugated paper box, additional information about waste management, and additional handle. Based on the sustainability analysis using SolidWorks, the packaging material of the corrugated paper is the best-chosen material because it has the lowest effect of environmental impact compared to other packaging materials. According to the finite element analysis using SolidWorks, the thickness of packaging and the packaging size are having better results based on the value of von Mises' stress, resultant displacement, and equivalent strain.

It is recommended to use standard experiments on simulations that have been carried out through software applications, such as stress tests, resultant displacement tests, and strain tests. Furthermore, drop and lift tests are also required according to the standards using a simulator.

Data Availability

The customer survey data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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