CONCEPTUAL DESIGN OF 3D PRINTED COMPOSITE SIDE MIRROR BASE USING HYBRID METHOD

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DECLARATION

I declare that this thesis entitled "Conceptual Design of 3D Printed Composite Side Mirror Base Using Hybrid Method" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Muhammad Khairul Azmir Bin Ab Hamid

Date : 28 March 2024

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Mechanical Engineering.

Signature : ....

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Date : 28 March 2024

DEDICATION

First and foremost, I would like to dedicate this accomplishment to Allah s.w.t, the creator and everyone who has been part of this journey. Special thanks to my supervisor, Ts. Dr. Mohd Adrinata Bin Shaharuzaman for his guidance and wisdom that have helped me go through all obstacles in completing this thesis. To my beloved mums, Jamaliah Binti Ahmad and Rosnah Binti Rahmat; my other half Norfaizah and my beloved children Suri and Aslan, whose unwavering love, support, patience and understanding have been a constant source of my strength. Their belief in me has been a driving force behind the completion of this thesis. To my friends; Fara, Shazwan, Husharilamri, Syamil, Misa, Syamimi, Amir and Arshad, who stood by me with constant support and encouragement throughout the journey that has made me through it with ease and joy.

ABSTRACT

The research work presents the stages of producing a conceptual design of a side mirror base that is optimum in shape and utilizes an ideal amount of natural fiber composite, an environmentally friendly material that has the potential to substitute the existing plastic material that is harmful to the environment. To determine the best among five natural fiber composites which are PLA + wood, PLA + coconut, PLA + bamboo, PLA + silk & PETG + wood, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method was used. The material properties from previous research and static simulation results of the created 3D car side mirror base using SolidWorks software were used as the set criteria for the TOPSIS method. Next, The 3D model undergoes the topology optimization simulation using SolidWorks software to obtain the best percentage of material removal and the finalized created model was verified through a static simulation study to ensure the part will not fail. The finalized design was fabricated using the previously selected material through the Fused Deposition Modelling (FDM) method where the finalized model went through processes such as file conversion from CAD file to STL file, slicing, and adjustment of printing parameters before the final model was printed to obtain the end product. The physical form of the conceptual design was weighed to compute the weight reduction obtained when compared to the unoptimized model. Among the five studied natural fiber composites, the TOPSIS method analyzed PLA + wood as the best material for the optimized side mirror base with a 0.9375 performance score. The topology optimization simulation study identified that the best percentage of material removal is 20% and the finalized model was created based on this simulation result. The optimized model weighed at 68.572g and was 11.235g or about 16.38% lighter than the unoptimized model. The TOPSIS method is a useful tool to make decisions involving multiple criteria while topology optimization is a great strategy to produce optimum design. Even if the result of topology optimization comes in complex geometries, the advancement of additive manufacturing such as FDM 3D printing can be utilized to fabricate the end product. The end product of this study is ready to be produced in either small or large scale as the environmentally friendly after-market substitution part to have a significant impact towards world sustainability.

REKABENTUK KONSEP CETAKAN 3D TAPAK CERMIN SISI KOMPOSIT MENGGUNAKAN KAEDAH HIBRID

ABSTRAK

Kajian ini membentangkan proses penghasilan reka bentuk konsep tapak cermin sisi kereta yang memiliki bentuk yang optimum dan menggunakan jumlah komposit gentian asli, iaitu sejenis bahan mesra alam yang berpotensi untuk menggantikan penggunaan plastik pada model sedia ada di pasaran yang mana berbahaya kepada persekitaran. Untuk memilih yang terbaik di antara 5 komposit gentian asli iaitu PLA + kayu, PLA + kelapa, PLA + buluh, PLA + sutera dan PETG + kayu, kaedah Teknik Susunan Keutamaan mengikut Penyelesaian Ideal (TOPSIS) telah digunakan. Sifat-sifat bahan yang diambil daripada kajian terdahulu dan hasil simulasi statik tapak cermin sisi kereta 3D yang dibangunkan menggunakan perisian SolidWorks telah digunakan sebagai kriteria penentuan kedudukan kesesuaian bahan menggunakan kaedah TOPSIS. Seterusnya, Model 3D tapak cermin sisi kenderaan menjalani proses simulasi pengoptimuman topologi menggunakan perisian SolidWorks untuk mendapatkan peratusan terbaik bahan yang boleh disingkirkan bagi menghasilkan rekabentuk yang optimum dan seterusnya rekabentuk model akhir yang dihasilkan disahkan kebolehfungsiannya melalui simulasi statik menggunakan perisian SolidWorks. Kemudian, reka bentuk akhir yang dimuktamadkan telah difabrikasi menggunakan bahan yang dipilih sebelum ini melalui kaedah cetakan 3D Fused Deposition Modeling (FDM) melalui proses seperti penukaran format fail model daripada CAD ke STL, pemotongan model dan penetapan parameter cetakan dan akhirnya proses cetakan menghasilkan model akhir dalam bentuk fizikal yang kemudiannya ditimbang untuk pengiraan pengurangan berat yang berjaya diperolehi berbanding model yang tidak menjalani proses pengoptimuman. Antara 5 komposit gentian asli yang dikaji, kaedah TOPSIS mengenalpasti PLA + kayu sebagai bahan terbaik untuk digunakan bagi menghasilkan rekabentuk konsep tapak cermin sisi kenderaan dengan skor prestasi 0.9375. Kajian simulasi pengoptimuman topologi juga mengenal pasti bahawa nilai terbaik bagi peratusan penyingkiran bahan ialah sebanyak 20% dan rekabentuk akhir model yang dimuktamadkan telah dibuat berdasarkan hasil simulasi ini. Model akhir yang dihasilkan memiliki berat akhir sebanyak 68.572g, iaitu 11.235g atau kira-kira 16.38% lebih ringan daripada model yang tidak dioptimumkan. Kaedah TOPSIS terbukti sebagai teknik yang berguna dalam membantu penyelidik untuk membuat keputusan yang melibatkan pelbagai kriteria. Pengoptimuman topologi adalah strategi yang amat sesuai digunakan bagi menghasilkan reka bentuk produk yang optimum. Untuk hasil pengoptimuman topologi yang berbentuk geometri yang kompleks, kaedah seperti percetakan 3D FDM boleh diaplikasikan untuk menghasilkan produk akhir dalam bentuk fizikal. Produk akhir hasil daripada kajian ini sedia untuk dihasilkan secara tempahan individu atau secara pukal bagi menghasilkan produk gantian alternatif yang mesra alam sekitar yang berupaya memberi impak yang menjamin kelestarian bumi.

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LIST OF ABBREVIATIONS

3D	-	Three Dimensional
AHP	-	Analytical Hierarchal Process
AM	-	Additive Manufacturing
ANP	-	Analytical Network Process
CAD	-	Computer-Aided Design
DEA	-	Data Envelope Analysis
DO	-	Design Optimization
ECER	-	Energy Conservation and Emission Reduction
EV	-	Electric Vehicle
FDM	-	Fused Deposition Modelling
FEA	-	Finite Element Analysis
FFF	-	Fused Fillament Fabrication
MCDM	-	Multiple-Criteria Decision-Making
MM-AM	-	Multi-Material Additive Manufacturing
NFPC	-	Natural Fiber Polymer Composite
PETG	-	Polyethylene Terephthalate Glycol
PLA	-	Polylactic Acid
STL	-	Stereo Lithography
TO	-	Topology Optimization
TOPSIS	-	Technique for Order of Preference by Similarity to Ideal Solution
UTeM	-	Universiti Teknikal Malaysia Melaka

LIST OF SYMBOLS

CO_2	-	Carbon Dioxide
RM/kg	-	Malaysian Ringgit per kilogram
MPa	-	Mega Pascal
GPa	-	Giga Pascal
g	-	gram
kg	-	kilogram
mm	-	milimeter
mm/s	-	Milimeter per second
$\circ$	-	Degree
C	-	Celcius
%	-	Percent
M	-	Determined alternatives for TOPSIS evaluation matrix
N	-	Determined criteria for TOPSIS evaluation matrix
α_{ij}	-	Normalized evaluation value
S_i^+	-	Euclidean distance that separates the target option from the best option
S_i^-	-	Euclidean distance that separates the target option from the worst option
a_{ij}	-	Value of evaluation matrix
x_{ij}	-	Weighted normalized decision matrix
w_j	-	Weightage of criteria
χ_j^b	-	Best criterion option

χ_j^w	-	Worst criterion option
P_i	-	Performance score of each material

CHAPTER 1

INTRODUCTION

1.1 Research Background

Vehicle side mirror is a component that is attached to the outside of automobiles allowing the driver to see areas behind and to the sides of the vehicle. One of the major parts that are vital to the complete side mirror assembly is the side mirror base, a part that holds the mirror in its suitable position. Typically made from plastics that are harmful to the environment, fewer studies have been conducted to optimize the side mirror base and many other plastic parts of a vehicle. Substitution to eco-friendly materials and design optimization to reduce its weight and material usage are the strategies to produce parts that contribute to overall vehicle weight. Less weight of the parts contributes to overall vehicle weight reductions that will require less power to energize the vehicle.

This study utilizes the combination of three (3) main strategies to reduce the material usage and the weight of the side mirror base, which are performing topology optimization to the current design that helps to optimize and eliminate unnecessary weight from it, using eco-friendly and lightweight natural fiber composite as material, and adapting advanced manufacturing technologies to produce the optimized end product that comes in the shape of complex geometry that is hard to produce using plastic injection moulding. The existing side mirror base of Perodua Myvi Model 2023 went through the Topology Optimization (TO) process using SolidWorks software. This shape optimization technique uses computational models to optimize material placement inside a user-defined region. It maximizes the performance and efficiency of the design by removing unnecessary material from locations that do not need to carry substantial loads. The results of topology optimization are in the shape of complex geometries and free forms that require the utilization of additive manufacturing technologies to produce the optimized part with intricate shapes and geometries.

The obtained result is then 3D-printed using the best natural fiber composite, which was selected using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method. The use of natural fiber composites as material replacing the existing harmful plastic material benefits the composite's advantageous feature which is environmentally friendly, lightweight and high strength-to-weight ratio. The results of this study are seen to be in line with the way forward of the automotive industry, which is the production of vehicles that are light, cost-effective, energy-efficient and at the same time do not pollute the environment through the use of environmentally friendly materials and optimal final product design.

1.2 Problem Statement

The automotive industry has always been targeted as one of the major contributors to the world's pollution. Recently, the rising concern of the world community towards the issue of earth sustainability has put more pressure on the stakeholders of the automotive industry to pay more attention to producing vehicles that are environmentally friendly holistically, starting from the production process to vehicle operations and disposal. One of the easiest ways to make significant progress towards achieving that vision is by substituting the non-eco-friendly plastic parts of vehicles with materials that are not harmful to the environment.

However, fewer studies have been conducted in the past towards utilizing environmentally friendly materials specifically on vehicle parts, understandably due to certain limitations such as manufacturing costs and technology.

Based on this gap, the study aims to explore the use of eco-friendly natural fiber composites in producing one of the most common plastic parts in vehicles which is the side mirror base. The best material to be used will be determined using the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) method, and the best design that uses optimum material will be finalized by utilizing the topology optimization study using SolidWorks software. Topology optimization is widely used in various industries to obtain the optimum shape of the studied parts, which are lighter in weight, use less material and sometimes reduce the size of the parts in the automotive industry, using less material in parts means producing lighter parts that will contribute not only to less manufacturing cost and time but will also improve the vehicle's performance (Xiong *et al.*, 2021). Less weight means it will require less energy consumption for vehicles to move, hence it will give a better travelling range when compared to heavier overall vehicle weight. Although to obtain significant production costs and vehicle weight reductions, researchers are focusing more on improving major parts that contribute the most weight in vehicles, such as various body parts, chassis, interior and power train applications (Gardie et al., 2021; Xiong et al., 2021), but the design optimization study conducted on minor parts of the vehicles also contributes to overall vehicle power-to-weight ratio, especially when it they are all accumulated together.

1.3 Research Question

From the problem statement explained, the research questions arise are as follows:

i. What is the best natural fiber composite material to be used as the eco-friendly side mirror base using the TOPSIS method?

ii. What is the optimum percentage of material cutback of the side mirror base that undergoes the topology optimization?

iii. How much weight reduction will be obtained by applying topology optimization on the side mirror base?

1.4 Research Objective

The main aim of this research is to propose a conceptual design of a side mirror base made of eco-friendly material (biocomposite) using a hybrid method. Specifically, the objectives are as follows:

i. To analyse the best natural fibre composite material from previous research that will be used in producing the new 3D model side mirror base using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

ii. To evaluate the best material cutback of the side mirror base through topology optimization simulation.

iii. To compute the weight reduction of the newly optimized side mirror base design using the 3D printing method.

1.5 Scope of Research

The scope of this research is defined as follows:

i. The study is conducted using the side mirror base of a Perodua Myvi (2023)

ii. The best PLA-natural fiber composite to be used in the study is determined using the TOPSIS method.

iii. Development of a 3D model of a side mirror base using SolidWorks software.

iv. The topology optimization study is conducted using SolidWorks software to determine the best percentage of material cutback and the optimized design of the side mirror base.

v. Fabricating the new conceptual design of the side mirror base using Fused Deposition Modelling (FDM) 3D printing.

vi. Obtain the weight reduction of the 3D printed optimized design of the side mirror base when compared to the unoptimized side mirror base.

1.6 Thesis Outline

Based on the objectives previously presented and on the approach proposed before, this thesis is made up of five (5) chapters, which contents are summarized as follows:

i. Chapter 1 Introduction. This chapter presents the background of the study, research problems, objectives and scopes of research.

ii. Chapter 2 Literature review. This chapter starts with an overview of the vehicle's side mirror base. Then, the chapter presents various works of literature on composites and natural fiber composites. Next, this chapter presents an overview of the hybrid method and how multiple methods are used to produce better outcomes. Also, a brief discussion on the multiple-criteria decision-making method (MCDM) and the technique for order of preference by similarity to the ideal solution (TOPSIS), one of the MCDM methods that will be utilized in this study to help select the best materials to be used to fabricate the finalized design. A brief overview of how vehicle lightweighting is a continuous constant approach to producing a better car is reviewed next in this chapter. Moving on, this chapter continues with reviews of topology optimization as one of the design approaches to produce the optimum final product followed by how additive manufacturing and fused deposition modelling can help to produce the optimized end product that usually comes in the shape of complex geometry.

iii. Chapter 3 Methodology. This chapter presents the methodology that has been developed to produce the optimized design of the side mirror base. Methodologies of the various works to achieve the final design such as MCDM TOPSIS in selecting the best natural fiber composite, topology optimization on the existing side mirror base design to obtain the best material reduction without compromising the product's performance and fabricating the final design using 3D printing method to finally measures the weight reductions benefitted from the overall process.

iv. Chapter 4 Results and Discussion. In this chapter, the developed model has undergone Finite Element Analysis (FEA) simulations, Multiple-Criteria Decision-Making (MCDM) using the TOPSIS method and topology optimization (TO) simulations to determine the best material and optimized design and later the final design is fabricated using 3D printing method to analyze the obtained weight reduction. All results obtained from each process are presented and discussed in this chapter.

v. Chapter 5 Conclusion and Recommendations for Future Research. This chapter summarizes the main conclusions as well as achievements of the work undertaken in this research and suggests areas for future work.