APPLICATION OF BIO POLYMER REINFORCED WITH NATURAL FIBER FOR CAR DOOR PANEL

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APPLICATION OF BIO POLYMER REINFORCED WITH NATURAL FIBER FOR CAR DOOR PANEL

HEW XIAO JUN

Report submitted in partial fulfillment of the requirements
for the award of the degree of

Bachelor of Engineering (HONS.) in Manufacturing

Faculty of Manufacturing Engineering
UNIVERSITI MALAYSIA PAHANG

June 2016

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering (Hons) in Manufacturing.

Signature	:	
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Position	:	Lecturer
Date	:	6 June 2016

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotation and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Name : Hew Xiao Jun

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Date : 6 June 2016

ACKNOWLEDGEMENT

There are many problems that I had faced when gone through this final year project. To complete this final year project, I would like to take this opportunity to acknowledge the cooperation, effort and both moral and technical support from numerous people and organization that has evolved in this project.

This project is a golden opportunity for learning and self-development. I am lucky and honored to have a wonderful and respectful supervisor to lead me through in the completion of this project. I am deeply indebted to my guide Dr. Nanang Fatchurrohman CEng(UK)Mech for his suggestions and guidance, which helped me a lot in completing this project. I also express the depth of my appreciation to my honorable supervisor for spending his valuable time to review and examine my project at every stage.

Next, I express my sincere gratitude to my parents for bringing me up to this stage with love and encouragement. Without them, I would not able to live in this comfortable environment and focus on study and project. I am really thankful for their constant support and encouragement who had inspired me from the day I learned to read and write until what I have become now. I cannot find any appropriate words to express my appreciation for their support and faith in my ability to achieve my targets.

I would also like to thank all my friends who have been always helping and encouraging me during this period of project. I have no valuable words to express my appreciation but I will keep them in my heart.

Last but not least, many thanks and appreciation go to all the panels whom given me opinions and guidance that has improved my skills and knowledge by their comments.

ABSTRACT

Natural fiber reinforced with bio polymer composite has raised great interest in many sectors, especially in automotive industry. The automotive industry is currently transforming to "green" since sustainable development policies tend to broaden with the growing concern for the environment. These bio composites are fully recyclable and biodegradable as they can be completely decomposed at the end of their useful life. They posses low density and satisfactory mechanical properties. In this paper, Quality Function Deployment (QFD) and Analytical Hierarchy Process (AHP) methods were applied in the selection of the most optimum bio composites materials for car door panel. The material selection process was carried out based on product design specifications of the car door panel to meet the customer requirements as well as sustainability factors using the principles of Quality Function Deployment (QFD). Based on literature review, there are five combination of bio polymer matrix reinforced with natural fibers composites were identified as the alternatives materials. A four level of AHP hierarchy structure was constructed which consists of a main goal, five main criteria, seven sub-criteria and five alternative materials. The overall results revealed that poly lactic acid (PLA) reinforced with kenaf fiber is the most appropriate candidate composite material for car door panel based on the highest priority ranking score. Sensitivity analysis was also performed by varying the weight of the main criteria to prove the findings are not dependent on unclear decisions. Furthermore, Finite Element Analysis (FEA) was conducted to further validate the obtained results by determining stress and deformation. From all these analysis, it can be concluded that PLA reinforced kenaf fiber is the best material which can use as the material for car door panel among all the other alternatives materials.

ABSTRAK

Komposit serat semula jadi yang diperkukuhkan dengan biopolimer telah menimbulkan minat yang besar dalam pelbagai sektor, terutamanya di dalam industri automotif. Kini, industri automotif telah mengubah ke arah "hijau" disebabkan dasar pembangunan yang mampan. Dasar pembanguan yang mampan ini adalah untuk meningkatkan kebimbangan manusia terhadap alam sekitar. Bio komposit ini boleh dikitar semula sepenuhnya dan mesra alam kerana ia boleh mereput sepenuhnya pada akhir hayat mereka. Mereka mempunyai ketumpatan yang rendah dan sifat-sifat mekanik yang memuaskan. Dalam kertas ini, kaedah Quality Function Deployment (QFD) dan Analytical Hierarchy Process (AHP) telah digunakan dalam pemilihan komposit bahan yang terbaik untuk panel pintu kereta. Proses pemilihan bahan telah dijalankan berdasarkan spesifikasi reka bentuk produk panel pintu kereta untuk memenuhi keperluan pelanggan serta faktor kemampanan dengan menggunakan prinsip-prinsip Quality Function Deployment (QFD). Berdasarkan kajian kesusasteraan, sebanyak lima jenis gabungan komposit biopolimer yang diperkukuh dengan serat semula jadi telah dikenal pasti sebagai bahan alternatif. Tahap empat struktur hierarki AHP juga telah dibina yang terdiri daripada matlamat utama, lima kriteria utama, tujuh sub-kriteria dan lima bahan-bahan alternatif. Keputusan keseluruhan mendedahkan bahawa poli asid laktik (PLA) diperkukuh dengan kenaf adalah calon bahan komposit yang paling sesuai untuk panel pintu kereta dengan berdasarkan ranking keutamaan skor yang tertinggi. Analisis sensitiviti juga dilakukan dengan mengubah berat badan pada kriteria utama untuk membuktikan keputusan penemuan tidak bergantung kepada keputusan yang tidak jelas. Tambahan pula, Finite Element Analysis (FEA) telah dijalankan untuk mengesahkan keputusan yang diperolehi dengan menentukan tekanan dan ubah bentuk. Dalam semua analisis ini, kesimpulannya adalah bahawa PLA diperkukuh dengan kenaf adalah bahan komposit yang terbaik untuk digunakan sebagai bahan panel pintu kereta di kalangan bahan alternatif.

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LIST OF SYMBOLS

a_j	Row vector of absolute weights for technical requirement
b_j	Row vector of relative weights for technical requirements
c_i	Column vector of importance to customer for the customer requirements
Rij	Weight assigned to the relationship matrix
λ_{max}	Principal eigenvalue of matrix A
w	Eigenvector
n	Dimension of matrix
CI	Consistency index
CR	Consistency ratio
RI	Random index
u	Initial velocity
v	Final velocity
t	Time when the vehicles stopped
F	*Force*
m	Mass
a	Acceleration
A	Area
l	Length
b	Breadth
P	Pressure

LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
ABS	Acrylonitrile-Butadiene-Styrene
AHP	Analytical Hierarchy Process
CAD	Computer-aided drafting
CAE	Computer-aided engineering
DFE	Design for Environment
ELV	End of Life Vehicles
FEA	Finite Element Analysis
HOQ	House of Quality
MCDM	Multiple Criteria Decision Making
PHA	Polyhydroxyalkanoates
PHB	Polyhydroxybutyrate
PHBV	Polyhydroxybutyrate co-hydroxyvalerate
PLA	Polylactic acid
PMC's	Polymer Matrix Composites
PP	Polypropylene
QFD	Quality Function Deployment

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In the Twenty-First Century, the growing use of materials has attached importance to one of the major issue of current industrial society. The consume of materials are rising rapidly to satisfy market demand. Manufacturers develop products with numbers of materials to fulfill their product functional requirement (Gessinger, 2009). However, these products may have a number of environmental impacts over its life cycle.

Sustainable Design or Eco Design has emerged in modern industry and becoming the main focus for future market (Hottle et al., 2013). Thereby, product designers are responsible to consider the environmental impacts associated with products and utilize Sustainable Design to reduce these environmental impacts through better design decisions.

Based on the study, a major of the automotive manufacturers are now using bio composites in various interior application. Bio composites are biodegradable composites that are made up of bio polymer matrix and reinforced with natural fibers. Generally, bio polymers reinforced with natural fibers are considered to be more environmental friendly. It possesses sufficient material specifications required to be used for automotive door panel. The bio composites have the potential to be applied as car door panel because they are low in cost, durable and light weight. These advantages would eventually lead to reduction in fuel consumption and energy emissions as compared to conventional plastic car door panel (Jiying Fan et al., 2011).

1.2 PROBLEM STATEMENT

Every product has environmental impacts. These environmental impacts of products, processes or services may include energy consumption, natural resource depletion, solid waste generation, air pollution, global warming and land degradation. These impacts can be minimized by practicing Sustainable Design which helps to improve product quality and cost while reducing environmental impacts. Sustainable development plays an important role in every industrial sector as well as in our lives. It helps to ensure the environment and natural resources are preserved for the sake of both present and future needs.

Besides, the concern on end-of-life vehicle recycling is widely utilized over the world. It is aimed to minimize the amount of waste generated from disposal process which also lead to reduce environmental impacts. Thus, every product and material design should include the end-of-life recycling factor in their product application.

Moreover. there are two major issues arise for the current materials for car door panel. These major issues are high cost and high weight. Hence, this research is attempted to evaluate bio composite materials and choose the most suitable composite materials for automotive interior door panel. Meanwhile, the final recommended composite material will perform finite element analysis (FEA) to justify the study.

1.3 OBJECTIVES OF THE RESEARCH

The objectives of this study are as follows:

1. To compile and identify the database of bio composite materials.
2. To rank the selection parameters based on the product performance and sustainability factors using Quality Function Deployment (QFD).
3. To perform Analytic Hierarchy Process (AHP) analysis to determine the best material for car door panel.
4. To validate the selected composite materials using Finite Element Analysis (FEA).

1.4 SIGNIFICANT OF RESEARCH

This study is significant in incorporating environmental considerations into product development process. The automotive door panel is designed to produce using environmental friendly composite materials and renewable energy. However, Design for Environment (DFE) or Sustainable Design is practiced to improve product quality and cost while reducing environmental impacts.

In addition, this study would combine with the studies in mechanical parameters, general properties, sustainability and manufacturability of various bio composite materials. Besides, material selection analysis is analyzed using Quality Function Deployment (QFD) and Analytical Hierarchy Process (AHP) software tool. By using these software, it is easier to analyze and make decision on choosing the best material for products. Moreover, Finite Element Analysis (FEA) has been carried out after material selection by using the final recommended natural fiber reinforced bio polymer composite material for validation of material properties.

1.5 SCOPE OF RESEARCH

This research of study focuses on material selection using bio polymer reinforced with natural fiber for automotive interior door panel. It can be considered as bio composite when bio polymer is reinforced with natural fiber. In this research, the mechanical parameters and sustainability factors of bio composite materials are collected to justify the interrelationships of mechanical parameters and sustainability factors for various types of bio composites based on the product performance. Moreover, Quality Function Deployment (QFD) and Analytic Hierarchy Process (AHP) analysis are used to determine the best bio composite material for automotive interior door panel. At the end of the research, Finite Element Analysis (FEA) is conducted to validate the material properties of the selected bio composite material.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Composite is a structural material that consists of two main components which are called the reinforcing phase and the matrix (Sanjay et al., 2015). The reinforcing phase materials are usually in the form of fibers or particles and has greater mechanical properties, while the matrix phase materials are always continuous and in bulk materials. However, the reinforcement of fibers and matrix can increase the strength and stiffness of the matrix. The existing information and knowledge shows the growing environmental concerns and regulations in automobile industry has lead to the replacement of synthetic fiber materials with natural fiber materials (Ahmed Ali et al., 2015). Based on this issue, some literature has been analyzed and studied on using bio composite materials for car door panel. A considerable amount of literature has been published on the mechanical properties of various Polymer Matrix Composites (PMC's) where various polymer-based resin will be reinforced with different types of natural fibers. Other studies have reviewed on multiple criteria decision making using Quality Function Deployment (QFD) and Analytic Hierarchy Process (AHP) to select the most appropriate material for car door panel. Furthermore, some literature on Finite Element Analysis (FEA) have been reviewed to understand the simulation method for validation of the selected composite material.

2.2 FUNCTION OF CAR DOOR PANEL

2.2.1 Car Door Panel

In general, a car door can be opened and closed to provide access to the opening or closing to secure (Rosli et al., 2013). They are typically hinged partition or sometimes attached by other mechanisms like tracks as sliding door. These doors can be either opened manually or power electronically. The powered car doors can be usually found on minivans and luxury cars.

Raghuveer & Prakash (2014) details out there are two sides of a car door namely interior side and exterior side of the door. The exterior side of the car door is typically exposed to the vehicle's exterior and colored with a decorative design appearance, while the interior side of the car door contributes to the overall functionality and ergonomics of the car ride. The interior side of the car door is also known as the car door panel. The interior car door panel is normally made up of a variety of materials. Those materials can be vinyl and leather or sometimes can be cloth and fabric. The choice of the material for car door panel is always intended to match the styles and materials used in the car's inner body equipment such as dashboard, seats, carpet and etc.

Dissimilar with the material used for exterior side of the car door, the interior car door panel need to consider both aesthetic appeal and coziness. Their overall function are associated with ergonomics of the ride, such as: armrests, door lock system, window control system, various switches and compartments for small items and bottle (Rosli et al., 2013).

2.2.2 Design considerations and Current materials of Car Door Panel

A comprehensive review from Zhang et al. (2010) reported that the safety of the car passengers can be enhanced by optimizing the interior car door panel's properties and design parameters. These design parameters include the elastic modulus and thickness of the interior car door panels. Moreover, the selection of appropriate material and thickness of car door panels can improve the car safety performance in a side collision.

Tay et al. (2014) presented the selection of materials is significant because the materials used in vehicles are serve as a structural reinforcement to absorb impact energy from transferring to the passengers. The effect of different properties of various materials will directly influences the vehicle crashworthiness. Hence, it can be concluded that the vehicle crashworthiness would be advantageous from materials with high energy absorption.

According to Ahmed Ali et al. (2013), natural fiber composites has arise to become a choice of materials for automotive interior components, such as: door panels, dashboards, seat backs and etc. Automotive manufacturer, Toyota has used kenaf fiber for their five interior components in 27 car models. These kenaf fiber composites are typically made from kenaf reinforced polypropylene (PP) or kenaf reinforced polylactic acid (PLA). In fact, the future material choice of automotive manufacturer, Ford would be sisal fiber reinforced polypropylene composite since it has already passed the crash and impact test requirements.

Faruk et al. (2014) reported natural fiber reinforced with synthetic polymer composites are used in car components by the European car manufacturers in the past decade. These natural fiber composites are replacing glass fiber and carbon fiber because of the winning parameters of natural fibers except for strength. These parameters are lower cost, weight reduction, low energy consumption and recyclability.

Fan (2011) narrated the luxury automotive manufacturer, Mercedes used bio composites as material for their car applications in order to eliminate environmental impacts and enhance biodegradability. They used jute based composites, banana fiber reinforced composites and some other bio composites for different car models.

Author	**Title of Paper**	**Contribution**	**Journal Name**
Rosli et al. (2013)	Integrated AHP-TRIZ innovation method for automotive door panel design	A car door can be opened and closed to provide access to the opening or closing to secure. They are typically hinged partition or sometimes attached by other mechanisms like tracks as sliding door panel.	International Journal of Engineering and Technology

Author	Title of Paper	Contribution	Journal Name
Raghuveer & Prakash (2014)	Design and Impact Analysis of a Car Door	Dissimilar with the material used for exterior side of the car door, the interior car door panel need to consider both aesthetic appeal and coziness. Interior car door panels are normally made by vinyl and leather or sometimes can be cloth and fabric.	Journal of Modern Engineering Research
Zhang et al. (2010)	Optimization of vehicle side interior panels for occupant safety in side impact	Selection of appropriate material and elastic modulus as well as thickness of car door panels can improve car safety performance.	International Journal of Crashworthiness
Tay et al. (2014)	A finite element analysis of high-energy absorption cellular materials in enhancing passive safety of road vehicles in side-impact accidents	The vehicle crashworthiness would be advantageous from materials with high energy absorption.	International Journal of Crashworthiness
Ahmed Ali et al. (2013)	Java based Expert System for Selection of Natural Fibre Composite Materials	Natural fiber composites has arise to become a choice of materials for automotive interior components.	Journal of Food, Agriculture and Environment

Author	Title of Paper	Contribution	Journal Name
Faruk et al. (2014)	Progress Report on Natural Fiber Reinforced Composites	Natural fiber composites are used in car components by the European car manufacturers in the past decade because of lower cost, weight reduction, low energy consumption and recyclability.	Macromolecular Materials and Engineering

2.3 MATERIAL CONCEPTUAL SELECTION

2.3.1 Significance of Material Conceptual Selection

Material selection is one of the significant phases in product design (Sakundarini et al., 2013). Material selection is aim to identify and determine the most appropriate material for manufacturing processes. The unique properties of each material can determine the quality and performance of the product. According to Sakundarini et al. (2013), there are five steps involved in material selection process. These steps are clarifying design model, evaluating material properties, selecting material candidate, evaluating and judging for optimal solution and proof checks.

Albiñana & Vila (2012) has reviewed a case study on the factors that influence decision making and consideration of the relations among the parameters of the whole product life cycle. The analysis defines a process that breaks the works down into steps and phases. Meanwhile, it specifies how to perform preliminary selection. From the study, it noted that the most appropriate alternative in the conceptual design will lead to greater productiveness throughout the whole project.

2.3.2 Requirements of Materials in Car Door Panel

Ghassemieh (2011) reviewed that the requirements of materials in automotive industry are greatly based on two major criteria. First, the selection of materials must be able to meet the requirements of customers and secondly, the material must be environmental friendly and concerns for the safety.

2.3.2.1 Lightweight

Manufacturers are moving towards to manufacture vehicle components and applications using lightweight materials as the development are highly emphasis on reducing greenhouse gases and improving fuel efficiency. According to Ghassemieh (2011), an estimation claims that fuel economy can be improve by 7% for every 10% of weight eliminated from a vehicle's total weight.

2.3.2.2 Cost

It is very important to consider the cost of the materials in selecting ideal material for a product. When implementing a new material for an existing product, cost is always the most important variables that determine the opportunity of the new material to be selected for vehicle applications. Ghassemieh (2011) reported that a lower material cost can based on their shorter manufacturing cycle time, better machinability, number of assembly parts, more easily produced to near net shape and good dimensional tolerances. These can lead to reduction cost in production, processing, finishing and etc. Mihael et al. (2010) narrated that although the costs of composite material may be higher, the reduction in number of parts for assembly and fuel costs saving make them more profitable.

2.3.2.3 Safety and crashworthiness

A comprehensive review from Ghassemieh (2011) denotes that there are two important safety concepts need to be consider in automotive industry. These two important safety concepts are crashworthiness and penetration resistance. Crashworthiness is defined as the ability to absorb impact energy through controlled failure modes whereas penetration resistance determines the total absorption without permitting projectile or fragment penetration.

A composite is a material combined of two or more different materials and lead to superior advantages and properties (Mihael et al. 2010). As opposed to metals, most of the fiber reinforced composite materials do not experience plastic deformation after impact while metals collapse and undergo plastic deformation easily under crush or impact (Ghassemieh, 2011). Composite materials which posses greater geometry of structure helps to develop high energy absorbing mechanisms. Hence, the material deformation and failure behavior with regard to yield, strength, stiffness, strain and elongation at break are significant in the energy absorption capacity of the vehicle.

2.3.2.4 Recycling and life cycle considerations

Another growing concerns in the automotive industry is the end-of-life requirements for vehicle or vehicle component parts. Ghassemieh (2011) has discussed about the current issue arise in the European and Asian country. European Union (E.U.) has implemented a legislation on a significant percentage of the vehicle should be re-used or recycled at the end of their life and meeting environmental standards. The End of Life Vehicles (ELV) has set a target to reduce the amount of waste Every year, around millions of vehicles in the world are reaching the end of their life. They are classified as hazardous wastes until they have been fully well treated.

Sakundarini et al. (2013) states the vehicle and vehicle components should posses higher recyclability at the end of their life in order to lengthen the use of materials. A review from Sakundarini et al. (2013) shows the current stage in environmental regulations and legislations on vehicle's end-of-life requirements, car manufacturers are struggling in manufacturing new vehicles and vehicle replacement parts with higher level of product's reuse, recycling and recovery targets and limit the use of hazardous materials (Ghassemieh, 2011).

Author	Title of Paper	Contribution	Journal Name
Sakundarini et al. (2013)	Optimal multi-material selection for lightweight design of automotive body assembly incorporating recyclability	Material selection is one of the significant phases in product design to identify and determine the most appropriate material for manufacturing processes.	Materials & Design
Albinana & Vila (2012)	A framework for concurrent material and process selection during conceptual product design stages	The most appropriate alternative in the conceptual selection will lead to greater productiveness throughout the whole project.	Materials & Design
Ghassemieh (2011)	Materials in Automotive Application , State of the Art and Prospects	Requirements of materials in car door panel: (1) Lightweight (2) Cost (3) Safety and crashworthiness (4) Recycling and life cycle considerations	New Trends and Developments in Automotive Industry

2.3.3 Multiple Criteria Decision Making in Material Selection

Jahan et al. (2010) proposed Multiple Criteria Decision Making (MCDM) is an excellent technique developed for material evaluation and selection. It is useful for engineers to select an ideal material for an engineering application. There are always more than one material is suitable for an application and the final selection is always a combination of both advantages and disadvantages. The conventional cost based approach or chart method are not an ideal method for material selection as they limit the decisions to only two or three criteria, while MCDM has greatly improve these problems and manage to solve the material selection problem effectively.

Mardani et al. (2015) reviewed MCDM has became a part of operations research tool. MCDM supports the subjective evaluation of performance criteria by concerning with the designing computational and mathematical tools. The study has reviewed MCDM is a complex decision making tool suggested for decision makers to choose the optimal probably options. It is a tool involving both quantitative and qualitative factors. The most significant advantage of MCDM is it is capable of addressing problems that are marked by different conflicting interests. This leads to more efficient in solving critical problems that are hard to be solved by using common ways. Thus, MCDM tools have been largely employed to evaluate alternatives and comparative analysis.

Sakundarini et al. (2013) applied MCDM method for their researches on lightweight design which integrates with recyclability for an automotive body assembly. The study demonstrated the steps of MCDM in selecting the best material by considering the function, lightweight and recyclability factors during the initial product design process. Other than that, MCDM also helps to evaluate other end-of-life alternatives criteria such as reuse, remanufacturing and refurbishment.

2.3.3.1 Quality Function Deployment (QFD)

Customer requirements are relatively important in building a quality product. Quality Function Deployment (QFD) is one of the most applicable technique that help to translate customer needs to designers. QFD has been found to be superior and relatively closer to customers far more than other techniques. It is a quality technique for detecting the defects at product design phase. Moreover, QFD is beneficial to quality product design in several ways. QFD encourages teamwork by bringing together multi-functional teams. It reduces the development time and costs as well as design cycles and changes. Meanwhile, QFD can clearly clarifies customer priorities for better advantage gained over the competitors. Critical criteria are to be identified for design parameter, so that the product planning becomes much easier. The flexibility of QFD has facilitated it to be the most suitable technique for designing customer focused quality (Shahin, 2015).

Scalice et al. (2012) introduced a QFD conceptual model (Figure 2. 1) to select a suitable material based on product requirements and material properties. The approach presented the QFD technique by first relates the design requirements for each components with material properties (Assessment matrix) and then performs material selection based on these material properties (Selection matrix).

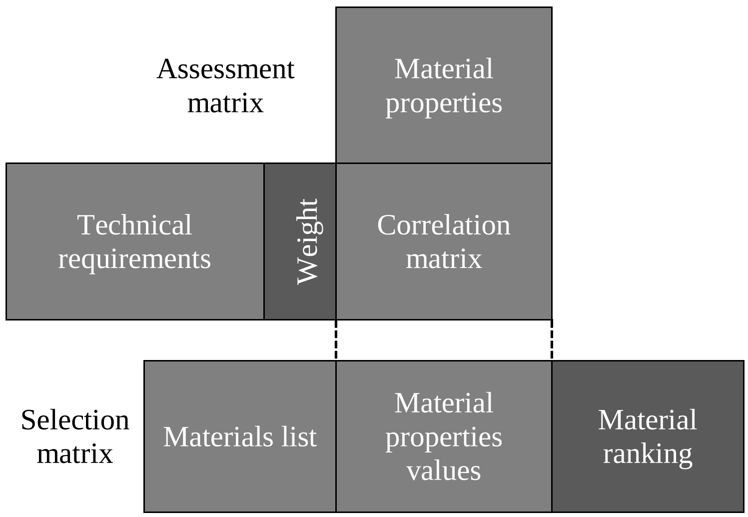


Figure 2.1: QFD conceptual model for material selection

Source: Scalice et al. (2012)

Nowadays, the acceptance of products by consumers are based on product quality and their environmental performance. Thus, Pusporini et al. (2013) proposed integrating environmental requirements into QFD methodology for creating and designing environmental friendly products. QFD concerns on construction of the house of quality (HOQ) and identification between customer needs and product characteristics. A detailed of HOQ structure (Figure 2. 2) would consist of six rooms which would transform customer needs into product characteristics or properties and then would be further deployed for process and production planning.

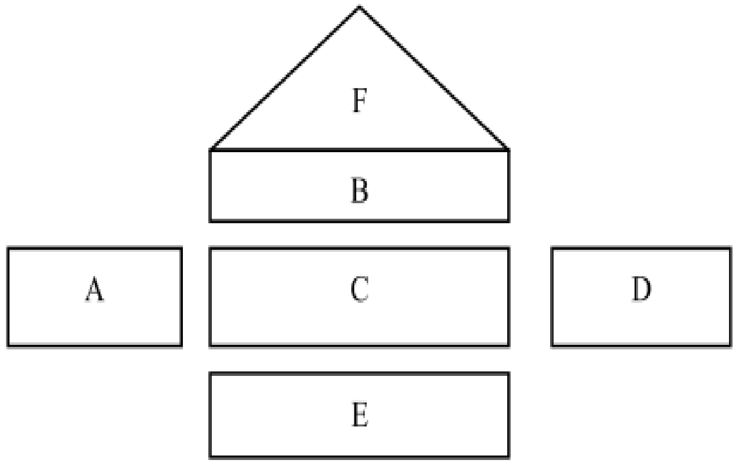


Figure 2.2: House of quality structure

Source: Pusporini et al. (2013)

A is customer requirements (Whats)
B is engineering characteristics (Hows)
C is the relationship between Whats and Hows
D is planning matrix
E is prioritizing characteristic engineering and target value
F is interrelationship between each engineering characteristic

Isaac & Olumide (2015) presented a modified HOQ to determine and select an appropriate material for the use in product design. Material screening and ranking processes are employed in a quantitative manner through a developed software to determine the best fitted material for the manufacture of the product. At the material screening and ranking stage, HOQ matrix was introduced to identify which material properties of the available materials are important for the product as illustrated in Figure 2.3.

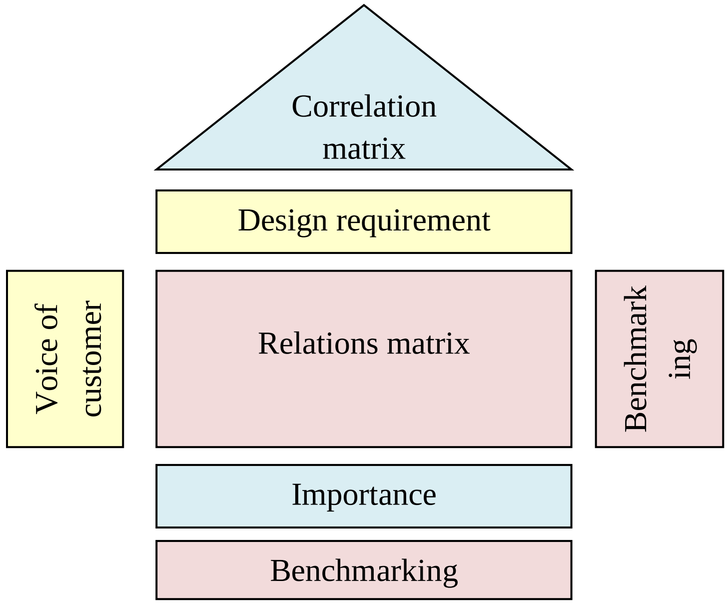


Figure 2.3: Modified HOQ for material selection

Source: Isaac & Olumide (2015)

2.3.3.2 Analytical Hierarchy Process (AHP)

Rosli et al. (2013) proposed Analytical Hierarchy Process (AHP) is intended to rank ideas and select the most ideal selection for the next stages. AHP is able evaluate and weight the criteria which have been identified in earlier stage. It is then combines each selected criteria of the generated ideas and thus optimizes the improved concept selection. Moreover, AHP helps to avoid cost waste and increase design efficiency during the product design and development stages.

Mansor et al. (2013) proposed AHP method in the selection of the most suitable thermoplastic polymer for natural fiber composites application. Based on the study, a four level AHP structure which consists of four main criteria and seven sub-criteria was employed. These four level AHP structure can be divided into (1) main goal- structure the decision problem, (2) main criteria- identify possible impact of each alternative, (3) sub-criteria- determine preference of decision, and (4) evaluate and compare decision alternative.

Furthermore, Ahmed Ali et al. (2015) carried out their researches on selecting optimum natural fiber reinforced composite materials using AHP method. They explored the implementation of AHP method using the expert software tool by considering main criteria and sub-criteria in the hierarchical model (Figure 2.4). The physical and mechanical properties are taken as the main criteria to identify the most appropriate material from various types of natural fiber composites materials. The selected material is able to meet the specifications of product properties and characteristics as well as cost factors. However, AHP method is only applied for positive reciprocal matrix. The computational procedures of AHP tool increases if the number of alternatives increases.

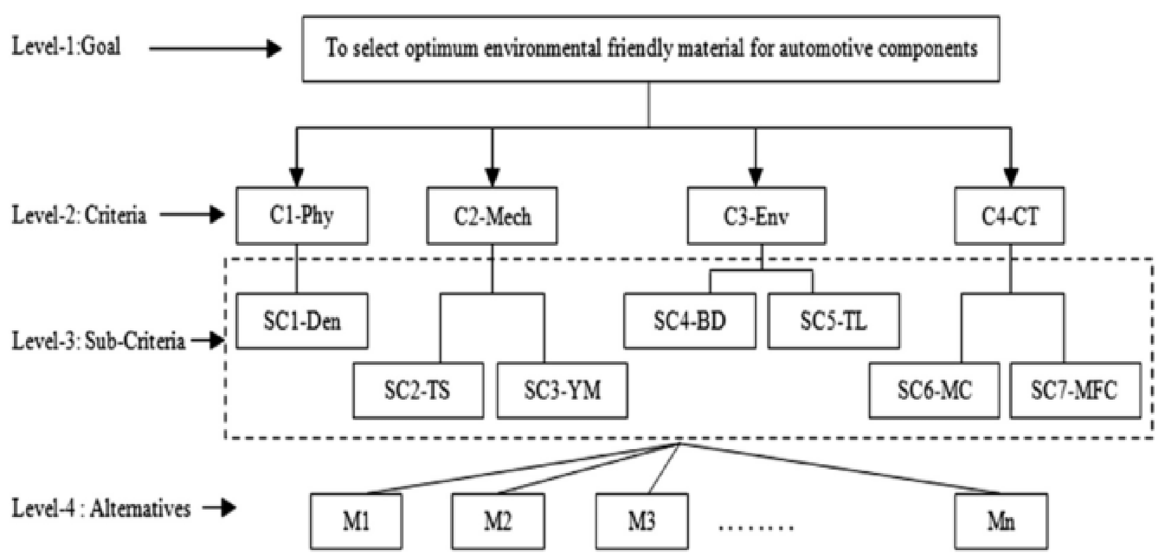


Figure 2.4: The hierarchical framework of AHP method.

Source: Ahmed Ali et al. (2015)

Author	Title of Paper	Contribution	Journal Name
Mardani et al. (2015)	Expert Systems with Applications Fuzzy multiple criteria decision-making techniques and applications	MCDM is widely used to evaluate alternatives and comparative analysis.	Expert system with applications
Sakundarini et al. (2013)	Optimal multi-material selection for lightweight design of automotive body assembly incorporating recyclability	MCDM method is applied for their researches on lightweight design which integrates with recyclability for an automotive body assembly.	Materials & Design
Scalice et al. (2012)	A knowledge-based material selector using Quality Function Deployment principles	QFD relates the design requirements for each components with material properties and then performs material selection based on these material properties.	Product Management & Development
Pusporini et al. (2013)	Integrating Environmental Requirements into Quality Function Deployment for Designing Eco-Friendly Product	QFD concerns on construction of the house of quality (HOQ) and identification between customer needs and product characteristics.	Materials, Mechanics and Manufacturing
Rosli et al. (2013)	Integrated AHP-TRIZ innovation method for automotive door panel design	AHP is intended to rank ideas and select the most ideal selection for the next stages.	International Journal of Engineering and Technology

Author	Title of Paper	Contribution	Journal Name
Mansor et al. (2013)	Material selection of thermoplastic matrix for hybrid natural fiber/glass fiber polymer composites	Four level AHP structure can be divided into: (1) main goal structure the decision problem (2) main criteria- identify possible impact of each alternative (3) sub-criteria- determine preference of decision (4) evaluate and compare decision alternative.	International Symposium on the Analytic Hierarchy Process 2013

2.4 NATURAL FIBER COMPOSITES

2.4.1 Matrix materials

The matrix is a continuous phase, which can be classified into polymer, metal or ceramic (Campbell, 2010). These matrix materials have different mechanical properties. Polymer has low strength and stiffness, metal has moderate strength and stiffness but high ductility, and ceramic has high strength and stiffness but brittle. The matrix is a substance that plays a role of holding the reinforcing materials together through fiber-matrix interface. Polymer and metal matrix composites transmit loads from matrix to fibers through fiber-matrix interface while ceramic matrix composites increase its toughness.

2.4.2 Significance of biodegradable polymers as matrix material

According to Ho et al. (2012), conventional polymers are inappropriate in product applications which has short product life cycle. These polymers require hundred years for deposit in a landfill after disposal and thereby increase the environmental burden. In 1980s, biodegradable polymers were introduced and designed to degrade upon disposal by the action of microorganisms. Yates & Barlow (2013) narrated that biopolymers are considered as an environmental friendly alternative to petroleum-based polymers due to the reintegration of resources used to produce them and their biodegradability to leave no waste product.

Chauhan (2012) presented that biopolymers are able to eliminate the emissions of carbon dioxide and degrade to organic wastes after disposal. At the end of the product's useful life, they can be decomposed relatively quickly with organic wastes and become nutrients for soil and the new growth of similar materials (Leja & Lewandowicz, 2010). Meanwhile, biopolymers could be recycled to useful resources. These helps to reduce waste, emissions and energy consumption.

Avérous & Pollet (2012) recounted that biodegradable polymers are in rapid growth for automotive industry. This is because biodegradable polymers has the potential to overcome the limitation of petrochemical resources in future. There are a large number of biodegradable polymers which include cellulose, starch, collagen, chitin, polylactic acid (PLA), polyhydroxyalkanoates (PHA), polyhydroxybutyrate (PHB) and other polypeptides. These biodegradable polymers can be classified as agro-polymers (starch, protein, cellulose, chitin and etc) and biodegradable polyesters (polylactide, polyhydroxyalkanoates and etc). The low environmental impact from the development of biodegradable polymers contributes significantly to a sustainable development for our future.

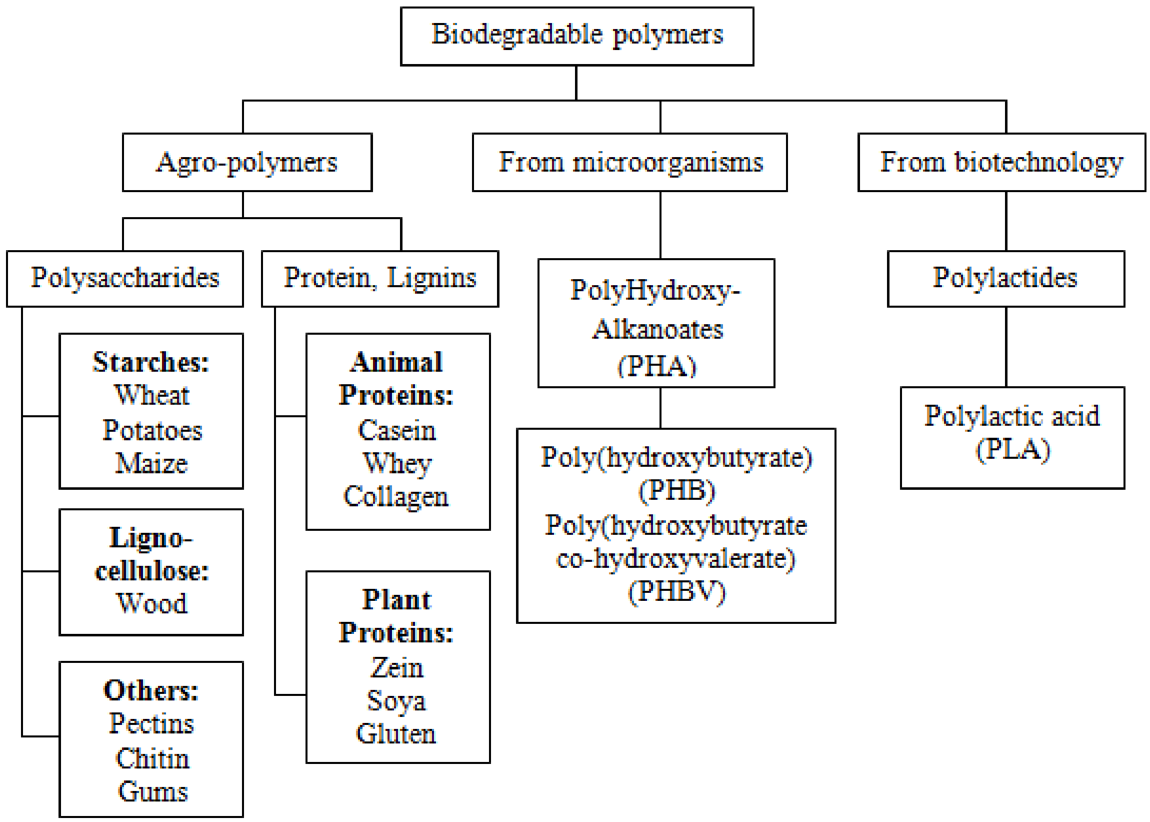


Figure 2.5: Classification of biodegradable polymers

Source: Avérous & Pollet (2012)

2.4.3 Reinforcement materials

Campbell (2010) states the reinforcing phase gives strength and stiffness. At most, the reinforcement materials has stronger, harder and stiffer properties than the matrix materials. The reinforcement materials are usually a fiber or particulate. These fiber or particulate composites are usually in the size of spherical, platelets or any regular or irregular geometry.

Faruk et al. (2012) indicate that there is an increased awareness where the non-renewable resources are turning into scarce and thus renewable resources has emerged. Generally, natural fibers are known as sustainable and renewable resources, but as a matter of fact, they are not. The living plants are sustainable and renewable from which natural fibers are adopted, but not fibers.

2.4.4 Significance of Natural fibers as reinforcement material

In the research article by Ho et al. (2012), they investigate natural fibers has become a new generation of reinforcement for polymer based materials. Natural fibers can be classified in terms of three main sources which are plants, animals and minerals. Figure 2.6 shows the classification of different types of natural fibers.

From the study on research conducted by Jauhari et al. (2015), we know that traditionally, natural fibers are used for low cost engineering application. Nevertheless, natural fibers are widely used as a substitute for synthetic fibers in automobile industry because they are sustainable, biodegradable and environmental friendly. These natural fibers include hemp, jute, kenaf, sisal, flax and many others (Sanjay et al. 2015).

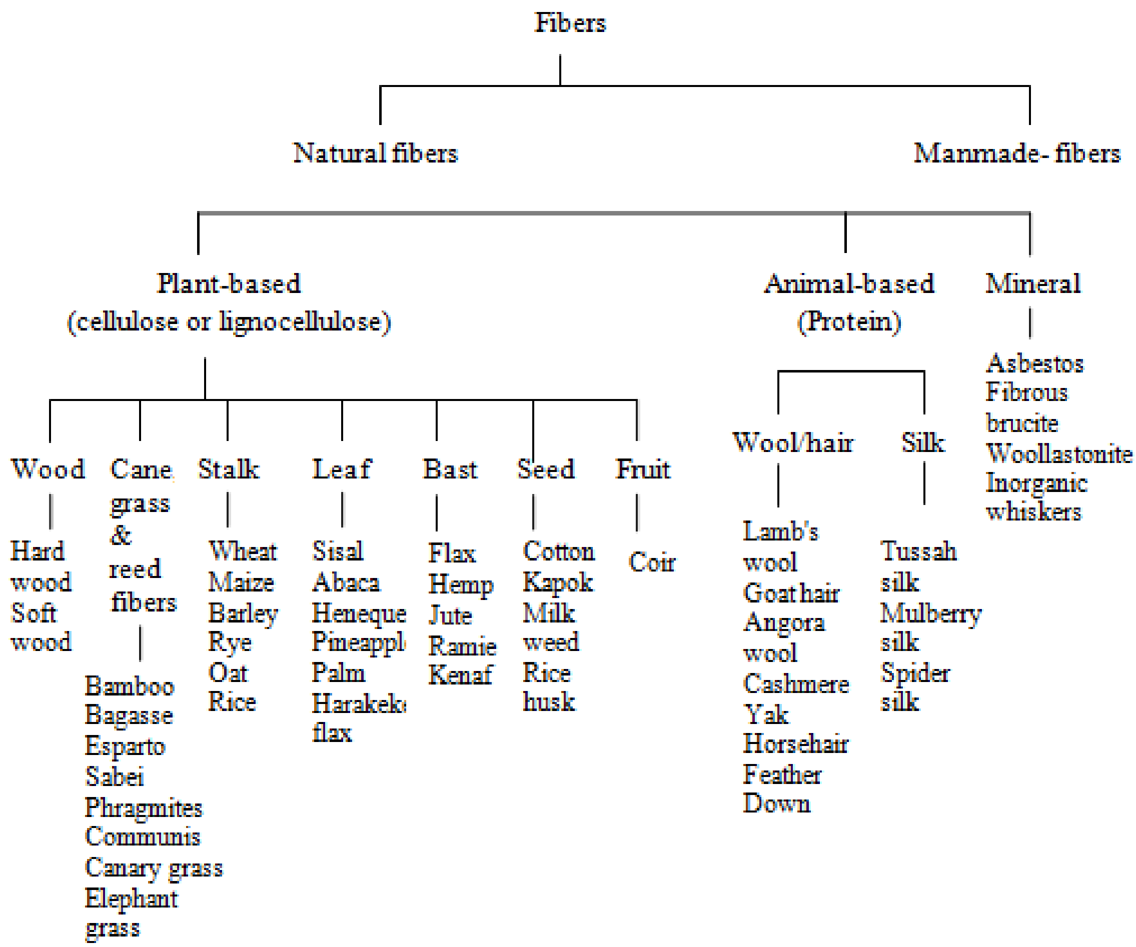


Figure 2.6: The classification of different natural fibers

Source: Ho et al. (2012)

Ismail et al. (2015) reported that the factors of consideration of fibers should not only depends on material properties, but also on its economic factor. Table 2.1 shows that natural fibers are advantageous over synthetic fibers in terms of density, tensile strength, Young's modulus, and elongation at break. Natural fibers is widely utilized as a reinforcement material in polymer composite due to its high strength and stiffness. The interfacial adhesion between fiber and matrix can influenced the properties of composites. The orientation of the fiber is one of the main factor that will affect the mechanical properties of composite. The fibers are hard to evenly distribute and manually separate during processing. Thus, the orientation of fibers must be in parallel direction in order to increase its Young's modulus and tensile strength.

Table 2.1: Physical and Mechanical properties of Natural and Synthetic Fibers

Fiber	Density (g/cm3)	Tensile strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)
Flax	1.5	345-1500	27.6	2.7-3.2
Hemp	1.47	690	70	1.6
Jute	1.3	393-800	13-26.5	1.16-1.5
Kenaf	1.22-1.44	930	53	1.6
Ramie	1.55	400-938	61.4-128	1.2-3.8
Sisal	1.45	468-700	9.4-22	3.1-7
Coir	1.15-1.46	131-220	4-Jun	15
E-glass (synthetic)	2.55	3400	73	2.5
Kevlar (synthetic)	1.44	3000	60	2.5-3.7
Carbon (synthetic)	1.78	3400-4800	230-240	1.4-1.8

Source: Ismail et al. (2015)

Ahmed Ali et al. (2015) concluded in their research study that natural fiber is a type of material that posses high environmental factors like sustainability, recyclability, biodegradability, low hazard level and less disposal factor. Therefore, the natural fiber composites are able to undergo degradation in natural environment. The research shows that natural fiber reinforced composites results in low cost and lightweight of automobile components meanwhile it improves the fuel efficiency and reduces emissions. Hence, natural fiber reinforced composite is beneficial to economical, social and environmental factors with its better advantages over synthetic fiber composite.

A review from Ismail et al. (2015) reported that kenaf fiber is typically used as a reinforcement in car door panels, dashboards and etc. Kenaf fibers have the advantages of higher tensile strength and flexural strength. Besides, kenaf fibers are also biodegradable and renewable which make them essential for manufacturing eco-friendly products.

Author	**Title of Paper**	**Contribution**	**Journal Name**
Campbell (2010)	Chapter 1: Introduction to Composite Materials	The continuous phase is the matrix, which are polymer, metal or ceramic. These matrix materials have different mechanical properties. The matrix is a substance that plays a role of holding the reinforcing materials together through fiber-matrix interface.	Manufacturing Processes for Advanced Composites
Yates & Barlow (2013)	Life cycle assessments of biodegradable, commercial biopolymers— A critical review	Biopolymers are considered as an environmental friendly alternative to petroleum-based polymers due to the reintegration of resources used to produce them and their biodegradability to leave no waste product.	Resources, Conservation and Recycling
Leja & Lewandowicz (2010)	Polymer biodegradation and biodegradable polymers - A review	Biopolymers can be decomposed relatively quickly with organic wastes and returned to enrich the soil. These helps to reduce waste, emissions and energy consumption..	Polish Journal of Environmental Studies

Author	Title of Paper	Contribution	Journal Name
Ho et al. (2012)	Composites : Part B Critical factors on manufacturing processes of natural fibre composites	Natural fibers has become a new generation of reinforcement for polymer based materials. It can be classified in terms of three main sources: plants, animals and minerals.	Composites : Part B
Jauhari et al. (2015)	Natural Fibre Reinforced Composite Laminates – A Review	Natural fibers are widely used as a substitute for synthetic fibers in automobile industry because they are sustainable, biodegradable and eco-friendly.	Materials Today: Proceedings
Ahmed Ali et al. (2015)	Implementation of the expert decision system for environmental assessment in composite materials selection for automotive components	Natural fibers posses high environmental factors like sustainability, recyclability, biodegradability, low hazard level and less disposal factor. Hence, natural fiber reinforced composite is beneficial to economical, social and environmental factors with its better advantages over synthetic fiber composite.	Journal of Cleaner Production
Ismail et al. (2015)	Review of the Compression Moulding of Natural Fiber-Reinforced Thermoset Composites : Material Processing and Characterisations	Kenaf fiber is typically used as a reinforcement in car door panels because of higher tensile strength and flexural strength. Kenaf fiber is also biodegradable and renewable.	Tropika Agricultural Science

2.4.5 Significance of bio composites

According to Fan et al. (2011), a totally natural, biodegradable and environmental friendly matrix and reinforcement composite materials will enhance the strength and biodegradability characteristics designed for the automotive applications.

Mukherjee & Kao (2011) proposed bio composites is the future of green composites delivering many sustainability issues. Polylactic acid (PLA) is the only biodegradable polymer that can produce at a large scale of over 140,000 tones every year. PLA reinforced natural fibers such as kenaf, flax, hemp, bamboo, jute, elephant grass and sisal can reduce weight, cost and carbon dioxide emission. They are recyclable and less reliance on foreign oil resources. However, there are several key factors that can affect the mechanical performance of bio composites: fiber length, fiber diameter, fiber volume fraction, fiber orientation, fiber surface treatment on fiber/matrix adhesion and processing methods. The authors indicated that the fiber diameter can affects the aspect ratio as well as decreases the mechanical performance of bio composites. Fiber diameter or length is inversely proportional to fiber strength. Long fiber and large diameter fiber results in poor fiber strength.

Faruk et al. (2012) investigated biopolymers reinforced natural fibers composites facilitates significant processing advantages, low cost, low relative density, high specific strength, fully biodegradability and renewable nature. In fact, the adhesion between fiber and biopolymer can affects the properties of composites and the overall performance. Mukherjee & Kao (2011) narrated several processing techniques and surface treatment of fibers matrix can helps to resolve the problem by improving the fiber matrix adhesion and the mechanical properties.

Moreover, Sahari & Sapuan (2011) evaluated the development and properties of bio composites. Natural fiber reinforced biodegradable polymer composites are capable to fully degrade and consistent with the environment. In Figure 2.7, it shows that the mechanical properties of PLA and flax fiber composites is about 50% higher than PP and flax fiber composites. This shows that natural fiber reinforced biodegradable polymer composites have a great potential for automotive applications.

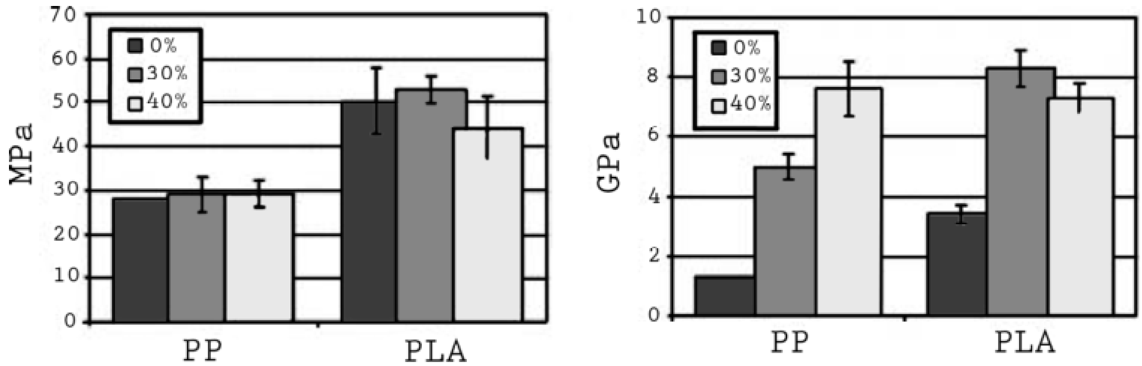


Figure 2.7: Tensile stress and tensile modulus of PLA/flax compared to PP/flax composites

Source: Sahari & Sapuan (2011)

John & Thomas (2008) denotes that automotive industry has largely used bio composites for vehicle interior applications because of the need to preserve the environment. Major automotive manufacturers in Germany such as Volkswagen, Ford, Mercedes, Audi, BMW, Daimler Chrysler and Opel are now use bio composites in their automotive interior applications. In year 1996, Mercedes began using jute based composites for car door panels. While DaimlerChrysler started using natural fibers composites for their vehicles in September 2000. They used bast fibers for their automotive applications as bast fibers exhibit the greatest strength. Another benefits of using bast fibers in automotive industry include weight savings of 10% and cost savings of 30%. Other than that, hemp fibers composites are also used in automotive applications due to its high specific stiffness.

Author	Title of Paper	Contribution	Journal Name
Fan et al. (2011)	New structural biocomposites for car applications	A totally natural and biodegradable composite materials will enhance the strength and biodegradability characteristics	Conference Proceedings, EUROTEC 20

Author	Title of Paper	Contribution	Journal Name
Mukherjee & Kao (2011)	PLA Based Biopolymer Reinforced with Natural Fibre: A Review	PLA is the only biopolymer that can produce at a large scale. Key factors that affects mechanical performance of bio composites: (1) Fiber length or diameter (2) Fiber volume fraction (3) Fiber orientation (4) Processing method	Journal of Polymers and the Environment
Faruk et al. (2012)	Biocomposites reinforced with natural fibers: 2000-2010	Advantages: 1) Low cost 2) Low relative density 3) High specific strength 4) Fully biodegradability 5) Renewable nature	Progress in Polymer Science

2.5 SIMULATION

Mushiri & Mbohwa (2014) details out the evaluation of the design of car door panel assembly using Finite Element Analysis (FEA) method. The purpose of the research is to design a new inner car door panel by reducing its weight and cost. Finite Element Method is applied in the research to predict the performance of the new car door panel design and optimize the design characteristics to meet the design targets. The design model is analyzed based on four performance indexes, which are strength, stiffness, modal characteristics and anti-extrusion. A car door panel model is first designed by Hyper mesh, and then imported into Nastran for simulation based on the performance indexes. Figure 2.8 shows the simulation result of the car door structure using FEA. With the implementation of Finite Element Method, it reduces the number of physical tests which also leads to minimize in development cycle and investment.

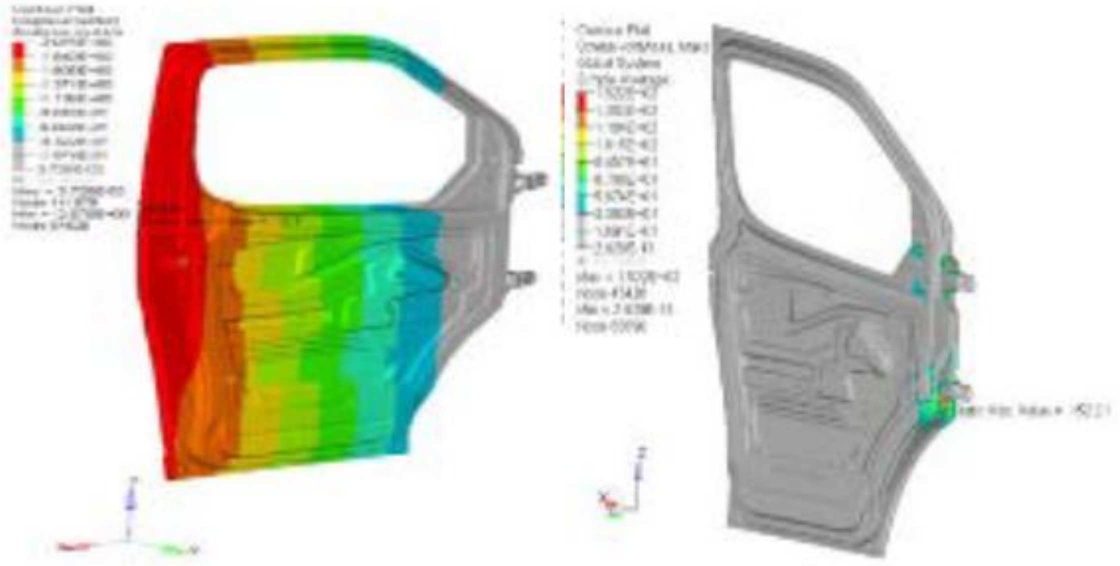


Figure 2.8: Door structure analysis result using Nastran software

Source: Mushiri & Mbohwa (2014)

Diwate & Deshmukh (2015) presented their research and analysis on the development of car door panel for passenger safety during side impact by using FEA tools. Firstly, they established a car door panel based on certain car model using a CAE software called Hypermesh 11. And then later on, they analyzed and evaluated the side impact simulation results using a FEA software called LS-Dyna solver. Finally, with the proposed CAE modeling and FEA methods, the verification and determination of side impact simulation for car door panel can be evaluated immediately. This resulted in reduction in overall development time and cost by preventing surprise failures in tests.

O.M. Terciu et al. (2012) narrated the investigation of a new composite materials used for an automotive door trim panel. They have applied Finite element analysis in their study to determine and simulate the mechanical behavior of car door trim panel made of different types of materials. The research presented the simulation results on stress distribution and displacement distribution on z-axis of car door trim panel as shown in Figure 2.9.

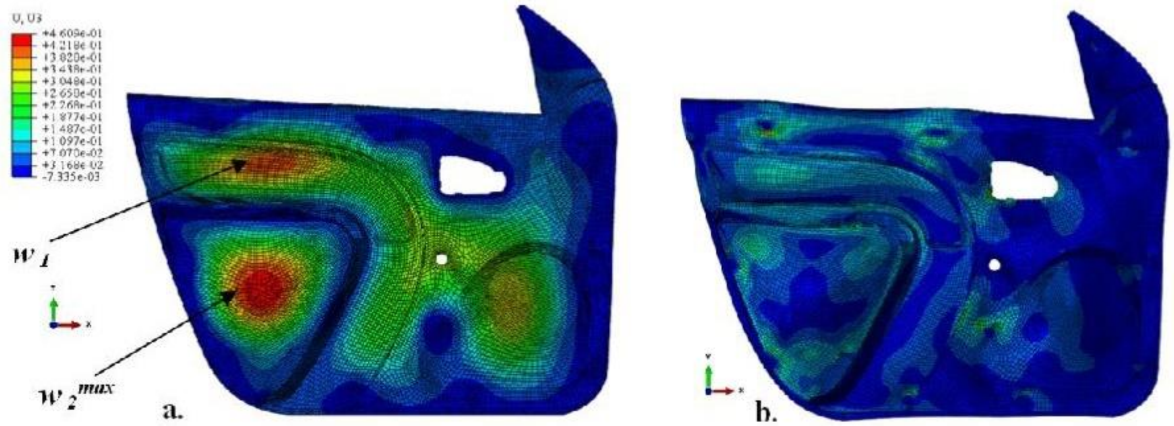
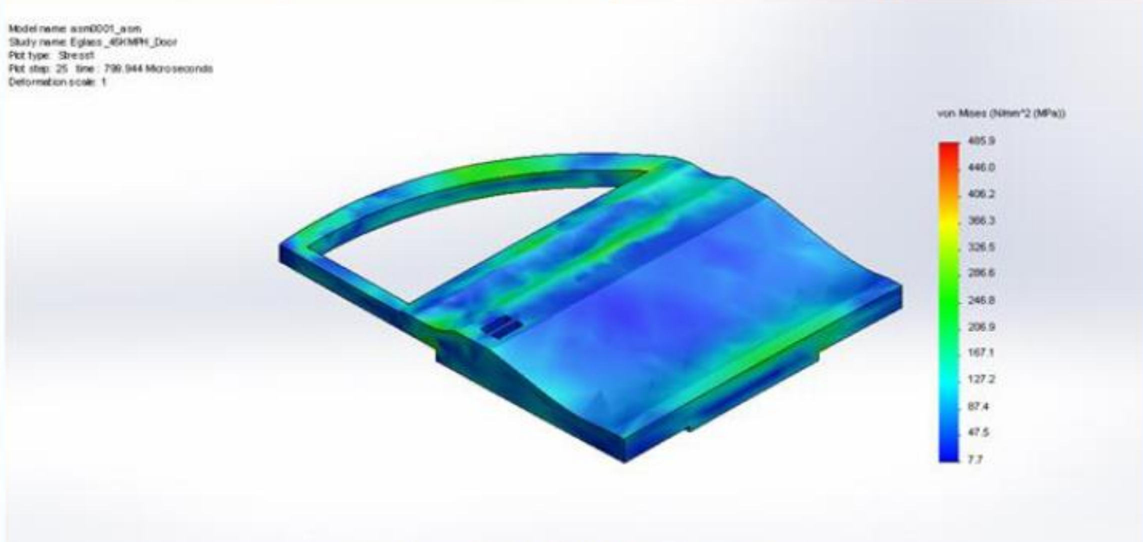


Figure 2.9: Displacement distribution on z-axis and Stress distribution of composite car door trim panel

Source: O.M. Terciu et al. (2012)

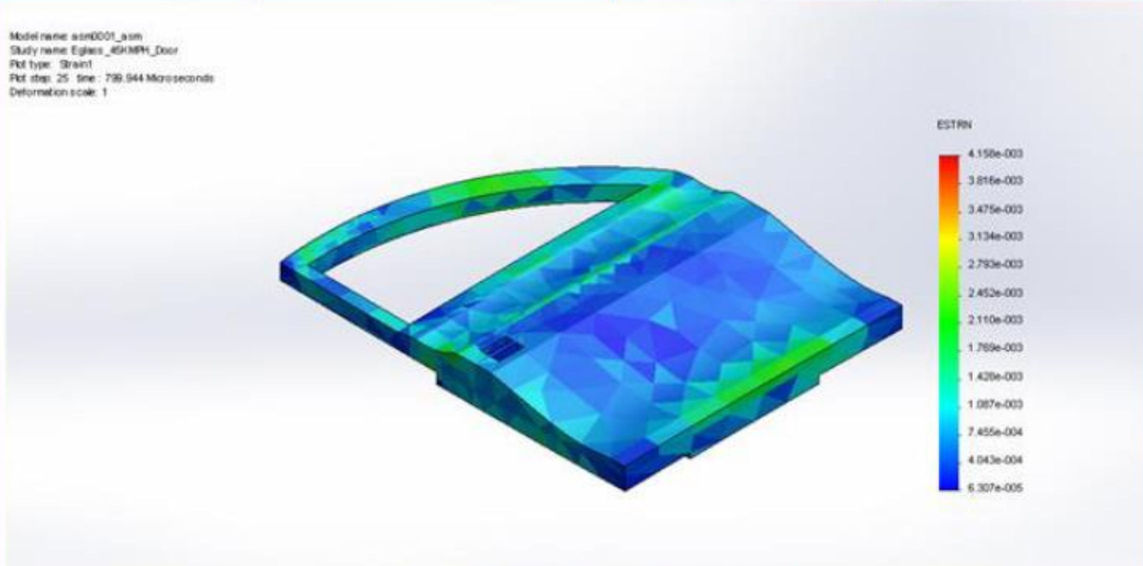
Raghuveer & Prakash (2014) reported the structural modifications that have been made using FEA method for a car door. The car door is designed and modeled using a CAD software called Pro-Engineer. In the structural analysis of the car door, they have studied on total deformation and von-masses stresses for three different types of materials using Solid works. The results obtained from the analysis help in reducing time consumed for material selection of a car door. From the results, it shows the maximum deformation and minimum deformation that might take place in the real model. The strength and strain are vary from types of materials. Figure 2.10 shows the 3D model stress and strain study results of the car door.

Name	Type	Min	Max
Stress1	VON: von Mises Stress	7.67429 N/mm^2 (MPa) Node: 7117	485.892 N/mm^2 (MPa) Node: 542



asm0001_asm-Eglass_45KMPH_Door-Stress-Stress1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	6.30705e-005 Element: 2372	0.00415769 Element: 1985



asm0001_asm-Eglass_45KMPH_Door-Strain-Strain1

Figure 2.10: Stress and Strain study of Car door

Source: Raghuveer & Prakash (2014)

Author	Title of Paper	Contribution	Journal Name
Mushiri & Mbohwa (2014)	Design of a Vehicle Door Structure Based on Finite Element Method	FEA is applied in the research to predict the performance of the new car door panel design and optimize the design characteristics to meet the design targets.	International Journal of Mechanical and Mechatronics Engineering
Diwate & Deshmukh (2015)	Development Of Passenger Vehicle Door Trim For Occupant Safety By Using CAE	FEA resulted in reduction in overall development time and cost by preventing surprise failures in tests.	International Journal of Scientific & Technology Research
O.M. Terciu et al. (2012)	FEM Modeling of an Automotive Door Trim Panel made of Lignocellulozic composites in case of a Door	FEA can determine and simulate the mechanical behavior of car door trim panel made of different types of materials.	Advanced Composite Materials Engineering
Raghuveer & Prakash (2014)	Design and Impact Analysis of a Car Door	The results obtained from FEA analysis help in reducing time consumed for material selection of a car door.	Journal of Modern Engineering Research

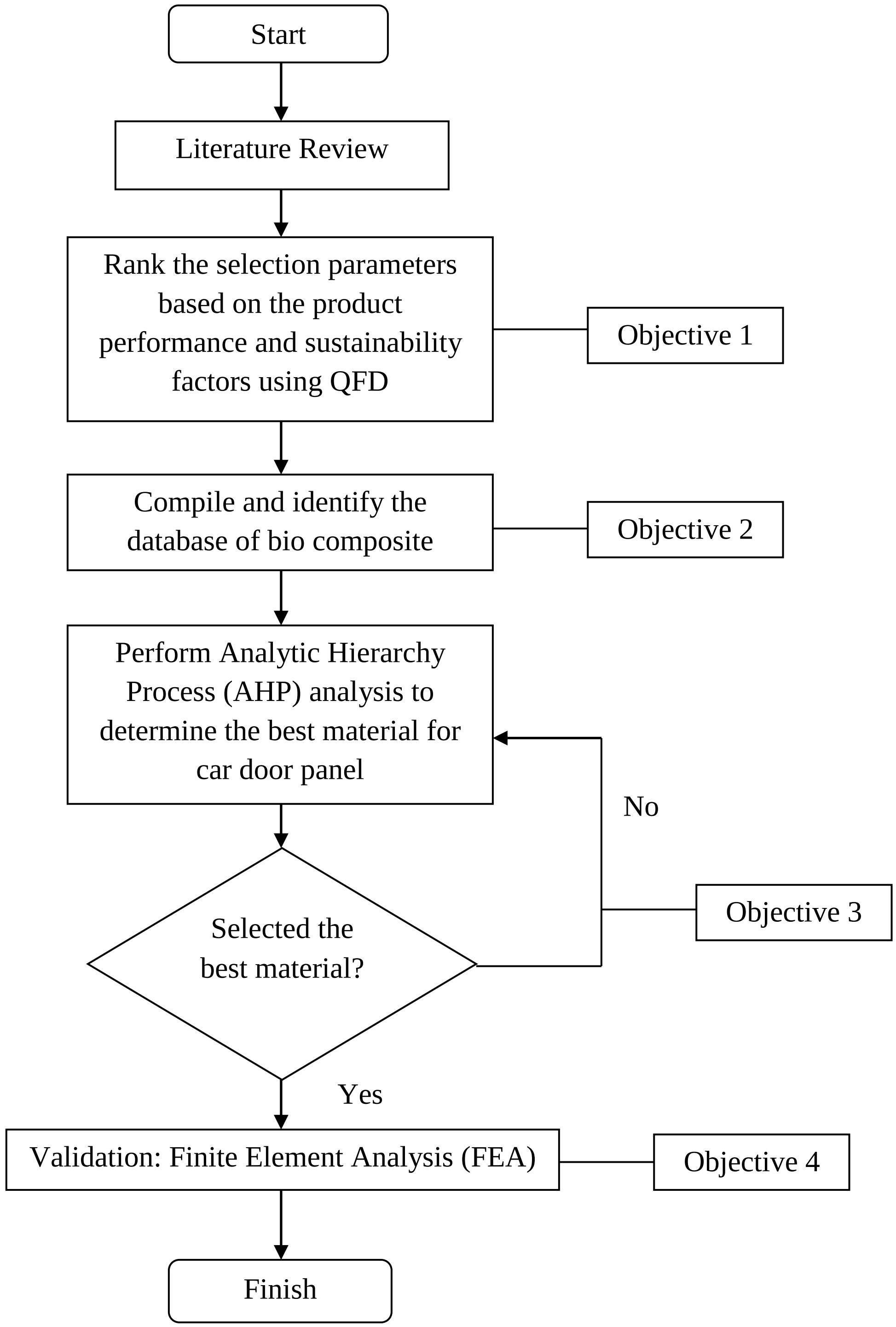
CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this section, a series of research methodology was applied to obtain the objectives of this study. The research methodology involves identifying the alternatives of bio composite materials, ranking the selection parameters based on the product performance and sustainability factors, determining the best material and conducting specimen testing using the selected bio composite. Multiple criteria decision making (MCDM) approach has been employed to help make better decisions for evaluating engineering problems. Both Quality Function Deployment (QFD) and Analytical Hierarchy Process (AHP) are the universal decision making method. They are aimed to help in developing new product by incorporating voice of customers into engineering product characteristics. The QFD is an comprehensive concept that help to translate customer needs into the appropriate technical or design requirements for further product development. The AHP is a multiple criteria decision making method for deriving relative priority from respective perception. These alternatives are able to deal with all sorts of interaction systematically. Consequently, QFD is good for making planning, whereas AHP is advantageous for evaluating alternatives. Lastly, extrusion and injection molding process were used to prepare bio composites. The reason of using these two processing techniques is to overcome the issue of fiber degradation occurs inside the extruder. When the test specimens is fabricated, several specimen tests were conducted to validate the mechanical properties of the selected bio composite.

FLOW CHART OF METHODOLOGY



3.2 MODELING OF CAR DOOR PANEL

The three-dimensional design drawing of car door panel as in this section was designed using CATIA V5R21 software. Figure 3.1 shows the original model of Proton Saga FLX. The car door panel Proton is fabricated by using Acrylonitrile-butadiene-styrene (ABS). This ABS made Proton door panel is fabricated through plastic injection molding. ABS is a high strength plastic commonly used by the car manufacturer to fabricate custom door panels. Unlike polyvinyl chloride (PVC), ABS has better impact resistance and high ductility.

Figure 3.1: Original model of car door panel of Proton Saga FLX

The CAD design modeling of the car door panel as illustrated in Figure 3.2 and Figure 3.3 was designed according to the dimension specifications of car door panel Proton Saga FLX. This design modeling is needed afterwards to conduct static structural analysis.

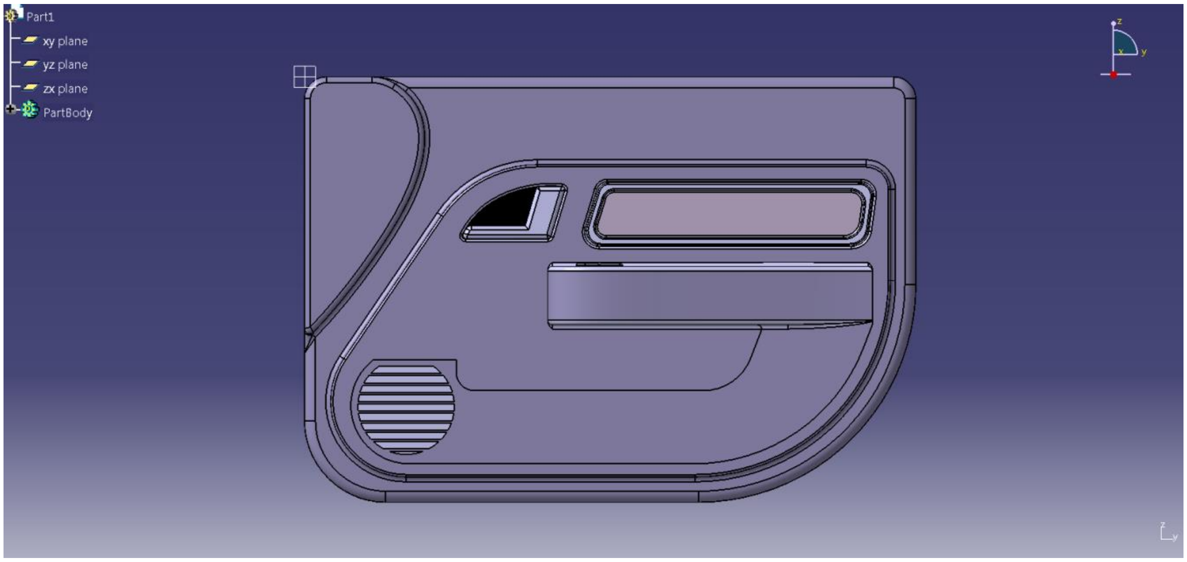


Figure 3.2: Front view of car door panel

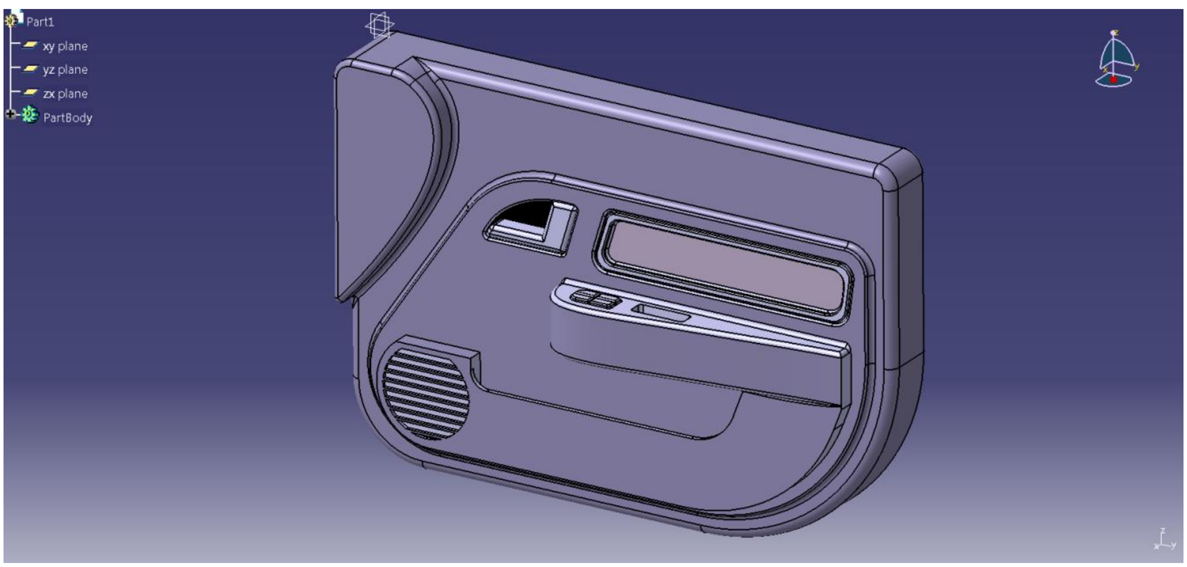
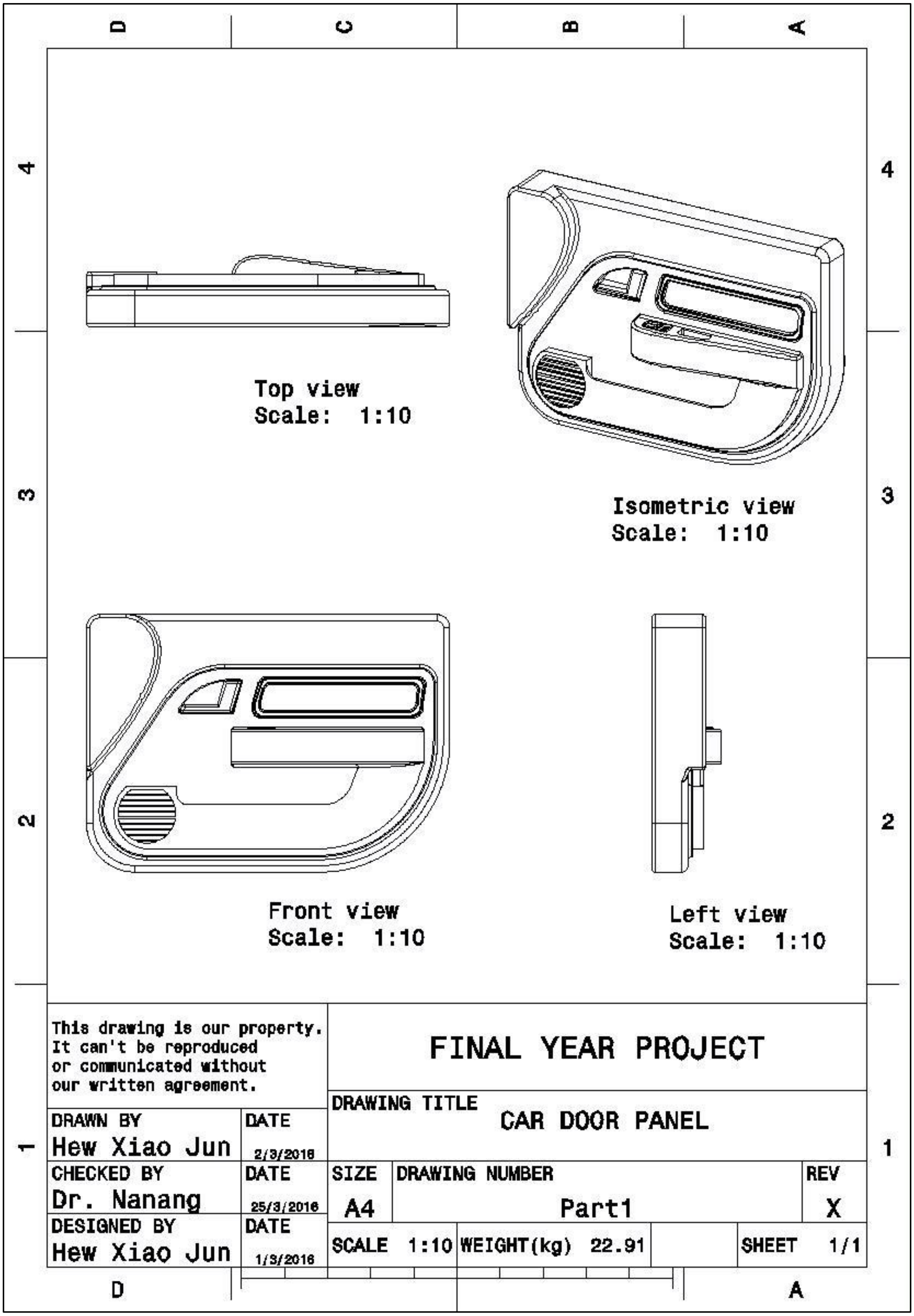


Figure 3.3: Isometric view of car door panel


D
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Top view
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Isometric view
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This drawing is our property. It can't be reproduced or communicated without our written agreement.
FINAL YEAR PROJECT
DRAWING TITLE
CAR DOOR PANEL
DRAWN BY
Hew Xiao Jun
DATE
2/3/2016
CHECKED BY
Dr. Nanang
DATE
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DESIGNED BY
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DATE
1/3/2016
SIZE
A4
DRAWING NUMBER
Part1
REV
X
SCALE 1:10
WEIGHT(kg) 22.91
SHEET 1/1

3.3 QUALITY FUNCTION DEPLOYMENT (QFD)

QFD was introduced by Professors Shigeru Mizuno and Yoji Akao in Japan around 1960s. QFD is aimed to translate customer requirements into an appropriate product requirements (Hammad et al., 2012). It can be defined as a tool for the development of products initiating from customer requirements and resulting in a systematic design specifications which directed to manufacturing activities.

In other words, QFD is a tool to transform the voice of customer into product design. It is also used for determining the priority of the tasks for a new product design. However, the results of QFD are just a guideline of determining the priorities. Thus, QFD must associate with AHP in order to reach a decision. A modified structure of house of quality (HOQ) is shown in Figure 3.3 to translate customer requirements into technical requirements.

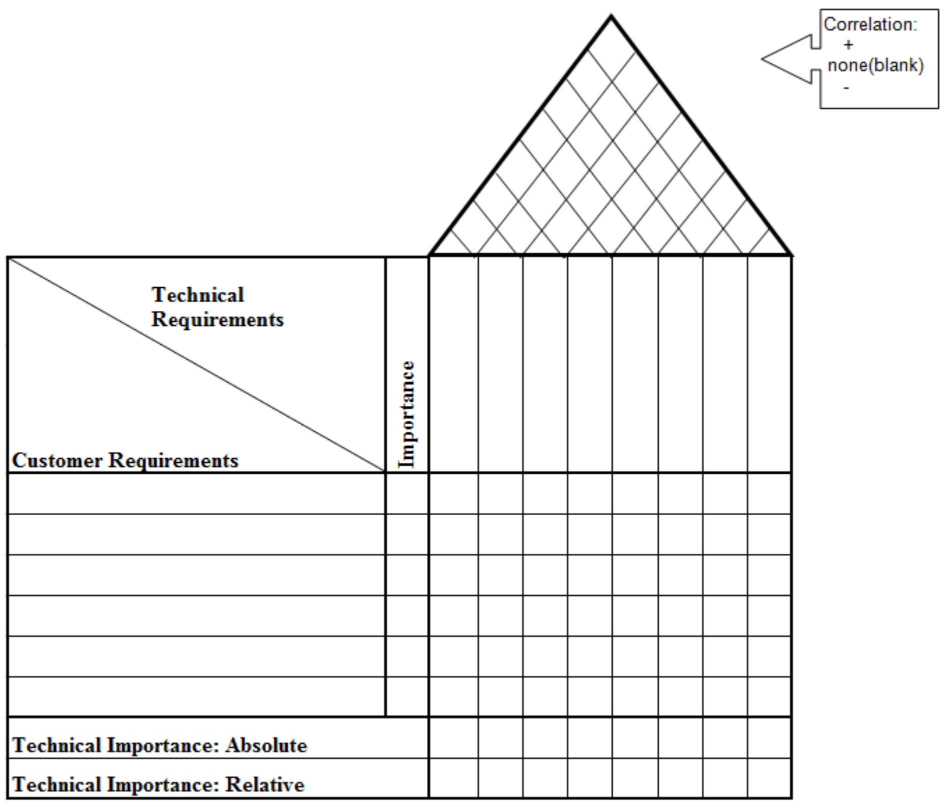


Figure 3.4: Modified Structure of House of Quality

There are a total of five steps involved in building the house of quality. These steps are illustrated as follows:

Step 1: Identification of customer requirements (WHATs).

QFD was always started with a list of goals. This list of goals was the customer requirements or voice of customer. It was often referred as the WHATs that a customer needs or expects in the design of a product. The list of customer requirements not only involved customer needs but also need to consider environmental factors. This environmental requirements would required recycling and life cycle consideration.

Step 2: Identification of technical requirements (HOWs).

The objective of QFD is to design or improve the design of a product so that it is able to meet or exceed the customer expectations. These expectations must be transformed into engineering characteristics or technical requirements (HOWs) to directly affect a customer perception. Each technical descriptors must be expressed in measurable terms to be easily directed to manufacturing activities.

Step 3: Develop a relationship matrix between customer requirements and technical requirements

In this step, the importance scale from 1 to 5 was used in considering the importance of the customer requirements to customer, where:

- 5 - the condition of the customer requirement is very important to customer
- 4 - the condition of the customer requirement is important to customer
- 3 - the condition of the customer requirement is mildly important to customer
- 2 - the condition of the customer requirement has low importance to customer
- 1 - the condition of the customer requirement has very low importance to customer

Next, the customer requirements (WHATs) would compare with technical requirements (HOWs) to determine their relationship matrix. It is structured in L-shaped matrix where the list of technical requirements is perpendicular to the list of customer requirements. Each relationship matrix between customer requirements and technical requirements will be assigned with a rating from 1 to 5 to indicate a rating of 1 for worst and 5 for best. These weights will be used in determining absolute weight of the matrix afterwards. The rating scale from 1 to 5 used in comparing the importance of the customer requirement with technical requirement is as follows:

- 5 - the condition of the customer requirement is very important to the design requirement
- 4 - the condition of the customer requirement is important for the design requirement
- 3 - the condition of the customer requirement is mildly important for the design requirement
- 2 - the condition of the customer requirement has low importance for the design requirement
- 1 - the condition of the customer requirement has very low importance to the design requirement

Step 4: Develop an interrelationship matrix between technical requirements

In this step, a roof of the house was constructed on the house of quality. This roof is called the correlation matrix. It is used to identify any interrelationship between each of the technical requirements. Two symbols were used to represent the degree of correlation between each of the technical requirements. These symbols were used in determining the strength of the correlation. If both of the technical requirements have positive correlation, a positive (+) sign would be assigned to the interrelationship matrix. Nevertheless, if both of the technical requirements have negative correlation, a negative (-) sign would be assigned to the interrelationship matrix.

Step 5: Develop prioritized technical requirement

The last step in QFD is making up a row corresponding to each technical requirement on the bottom side of the house of quality. This is to determine the prioritized technical requirements by calculating the absolute weight and relative weight.

The absolute weight for the *j*th technical requirements can be formulated as in Eq. (3.1).

$$a_j = \sum_{i=1}^{n} R_{ij} c_i \tag{3.1}$$

where

a_j = row vector of absolute weights for technical requirement

Rij = weight assigned to the relationship matrix (i = 1,..n, j = 1,..m)

c_i = column vector of importance to customer for the customer requirements

n = number of customer requirements

The relative weight for the *j*th technical requirements is given by Eq. (3.2).

$$b_j = {a_j}/{\sum a_j} \tag{3.2}$$

where

b_j = row vector of relative weights for technical requirements

a_j = row vector of absolute weights for technical requirement

3.4 ALTERNATIVES OF BIO COMPOSITES FOR CAR DOOR PANEL

The knowledge base of bio composites alternatives were gathered from handbooks, journals and published experimental works of researchers in the this advanced material field of study. In this research, it was to implement Super Decision system to analyze the alternative bio composite material by considering the mechanical and environmental factors.

Based on literature review in Chapter 2, it shows that the application of polylactic acid (PLA) is rapidly growing in the automotive industry. There are a total of five different natural fibers such as hemp, flax, sisal, jute and kenaf with a fiber content of 40% are considered as the reinforcement materials for PLA. The five main criteria to analyze the alternative material include performance, weight, cost, durability as well as recycling and life cycle consideration. Seven sub-criteria that were taken into consideration for selection are density (kg/m^3), tensile strength (MPa), young's modulus (GPa), flexural strength (MPa), flexural modulus (GPa), impact strength (kJ/m^2) and sustainability with a rating scale of 1-10 (worst to better). The database of bio polymer reinforced natural fiber composite was shown in Table 3.1.

According to the knowledge base gathered from literature review, the sustainability of flax or sisal reinforced PLA are poor compare to other alternative materials. So, a lower value of 6 was assigned. PLA reinforced kenaf has the best sustainability factor. Thus, a higher value of 9 was assigned.

Table 3.1: Database of alternatives of bio composite materials

Fiber	**Matrix**	**Density (kg/m^3)**	**Tensile strength (MPa)**	**Young modulus (GPa)**	**Flexural strength (MPa)**	**Flexural modulus (GPa)**	**Impact strength (kJ/m^2)**	**Sustainability**
Hemp	PLA	1020	77	10	104	5.78	19	7
Flax	PLA	1300	55	6.52	65.6	3.6	69	6
Sisal	PLA	1200	60	20	90	18	3.5	6
Jute	PLA	1350	72.7	4.6	84.5	7	15.8	8
Kenaf	PLA	1040	82	8	126	7.3	34	9

3.4.1 Previous Research Alternatives Materials for car door panel

A research was also carried out to study the previous alternative material for car door panel. From the literature review, it shows that synthetic polymers such as polypropylene (PP) and epoxy were previously used in the automotive industry. Table 3.2 illustrates the database obtained from the research of (Ahmed Ali et al. 2015).

Table 3.2: Database of previous research natural fiber composite materials

Fiber	Matrix	Density (kg/m^3)	Tensile strength (MPa)	Young modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Impact strength (kJ/m^2)	Sustainability
Kenaf	PP	1072	42	6.8	58	4	13.19	5
Jute	PP	1036	47	5.7	38	16.85	18.04	5
E-glass	PP	1150	31	7.9	36	12.65	18.5	4
Sisal	Epoxy	1044	32.7	4.3	290	22	33.71	4
Flax	Epoxy	1070	78.9	6.9	194	13	13.09	4

Source: Ahmed Ali et al.(2015)

3.5 ANALYTICAL HIERARCHY PROCESS (AHP)

AHP was developed around 1980s by Thomas Saaty. AHP is an effective analytical tool or technique for dealing with multiple criteria decision making (Hammad et al., 2012). It uses an interactive hierarchical structure for complex decision making. AHP helps to centralize both subjective and objective aspects of a decision by reducing multiple decisions into a series of pair wise alternatives and then integrating the results (Felice & Petrillo, 2010).

Generally, the AHP method that carried out in this study involved five main stages as shown in below.

Step 1: Developing AHP hierarchy framework

Initially, a four level of AHP hierarchy framework was developed for material selection. At level 1, the main goal was to select the best integration of bio polymer matrix reinforced with natural fiber materials. At level 2 and level 3, the material main criteria and sub-criteria were based on the customer requirements and technical requirements of the product respectively. These main criteria and sub-criteria are the customer requirements and technical requirements which have been identified previously from the developed QFD method. In AHP analysis, the hierarchy involved a total of five main criteria (performance, weight, cost, durability, and recycling and life cycle consideration) and eight sub-criteria (tensile strength, young's modulus, flexural strength, flexural modulus, density, impact strength, manufacturability, and sustainability). The weight of the car door panel can be affected by density, strength, modulus and sustainability. There are six sub-criteria that affects the performance of the car door panel: strength, modulus and density. Besides, density, manufacturability and sustainability will affect the costs. While impact toughness and recyclability are the two sub-criteria for sustainability. Lastly at level 4, all the identified alternatives are listed. These composite alternatives are hemp, flax, sisal, jute and kenaf reinforced with PLA respectively. A four level of hierarchy framework model is demonstrated in the Figure 3.4 as below.

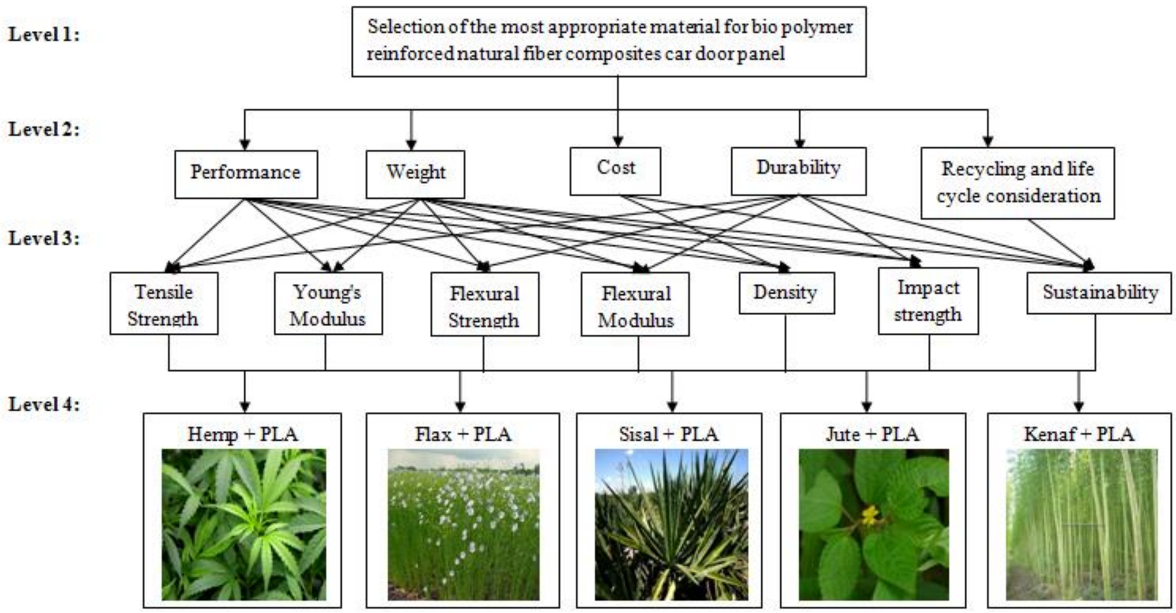


Figure 3.5: A four level of hierarchy framework model

Step 2: Construct and perform judgment of pair-wise comparison

In pair-wise comparison, scoring of the element in each level with respect to its parents is carried out to determine the relative importance with one to another. In each level, the elements are compared to its parents in pair-wise according to their levels of influence.

The relative scoring within each level is resulting in a matrix of scores *A(i, j)*.This pair-wise comparison matrix supports the judgment of the pair-wise comparisons and thus the judgment should be consistent. The appropriate inconsistency ratio should be less than or equal to 0.1 in order to be considered as reasonably consistent.

In general, the pair-wise comparison matrix *A(i, j)* is counted as consistent if all its elements follow the transitivity and reciprocity rules as follows in Eq. (3.3) and Eq. (3.4).

$$\boldsymbol{A}_{i,j} = \boldsymbol{A}_{i,k} \cdot \boldsymbol{A}_{k,j} \tag{3.3}$$

$$\boldsymbol{A}_{i,j} = \frac{1}{\boldsymbol{A}_{j,i}} \tag{3.4}$$

where i, j and k are the alternatives of the matrix.

The comparison of the two criterias C_i and C_j with respect to the goal can be made by asking two questions: which is more important and how much is the importance between the two elements C_i and C_j. According to Ahmed Ali et al. (2015), a relative importance scale of 1 to 9 is used in ranking of the best alternatives related to the overall priorities with respect to the main goal. The judgment made is based on the knowledge and justification through journals or handbooks. When the difference between the two elements is larger, a larger number is assigned to the pair-wise comparison. The standardized rating scale from 1 to 9 for pair-wise comparison was shown in Table 3.3.

Table 3.3: Rating scale for pair-wise comparisons

Relative intensity	**Definition**	**Explanation**
1	Equal importance	Two requirements are of equal value
2	Weak	Intermediate values, when compromise is needed
3	Moderate importance	Experience slightly favors one requirement over another
4	Moderate plus	Intermediate values between two adjacent judgments
5	Strong importance	Experience strongly favors one requirement over another
6	Strong plus	Intermediate values
7	Very strong importance	A requirement is strongly favored
8	Very, very strong importance	Intermediate values between two adjacent judgments
9	Extreme importance	The evidence favoring one over another is of the highest possible order of affirmation

Source: Ahmed Ali et al. (2015)

Step 3: Synthesizing and consistency analysis of pair-wise comparison

After performing judgment on pair-wise comparison, the next step is to analyze the priority vector or eigenvector. The pair-wise comparison matrix can also be represented as in Eq. (3.5).

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \quad (3.5)$$

For a consistent matrix, it can be demonstrated as in Eq. (3.6).

$$A = \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \times \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} \quad (3.6)$$

Or in a matrix form in Eq. (3.7).

$$A \cdot w = nw \quad (3.7)$$

where **A** is the comparison matrix, **w** is the eigenvector and **n** is the dimension of matrix.

For the consistent reciprocal matrix, the largest eigenvalue is equal to the number of comparisons, or $\lambda_{max} = n$, that is as expressed in Eq. (3.8).

$$A \cdot w = \lambda_{max} W \quad (3.8)$$

where $\boldsymbol{\lambda_{max}}$ is the principal eigenvalue of the matrix A.

To calculate consistency index (CI),

$$CI = (\lambda_{max} - n)/(n - 1) \quad (3.9)$$

To calculate the consistency ratio (CR), the equation is given in Eq. (3.10).

$$CR = CI/RI \quad (3.10)$$

where RI is the Random index of the same order matrix. The average random consistency index was tabulated in Table 3.4. For the results of consistency test, the consistency of judgment matrix was indicated as "consistent' if CR ≤ 0.1, else the judgment was inconsistent.

Table 3.4: Average random consistency index (RI)

Order of matrix	1	2	3	4	5	6	7	8	9
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Source: Ahmed Ali et al. (2015)

Step 4: Ranking the best alternative based on overall priority vector values with respect to the main goal

In the next step of the process, an overall priority ranking was performed to determine the best alternative. The numerical priorities were calculated for each of the alternatives with respect to the main goal. Hence, the optimum composite material for automotive door panel with performance and environmental evaluation was selected.

Step 5: Sensitivity analysis

The final step of the decision process is the sensitivity process. This sensitivity analysis was conducted to calibrate the judgment and further validate the final results obtained from AHP analysis. The sensitivity of the alternative rankings were analyzed by changing the priority of the criteria one by one. The vertical dotted line is always set initially at 0.5 on the x-axis whereas the respective priorities of the alternatives is demonstrated on the y-axis of the point where the alternative line intersects with the vertical dotted line.

3.6 VALIDATION: SIMULATION

3.6.1 Finite Element Analysis

Finite Element Analysis (FEA) is an impressively great computational tool used for examining and analyzing numerous structures such as doors (Darwish et al., 2012). It helps to save time and costs as compared to experimental tests. In the finite element method, a numerous structure is decomposed into small simple elements(S V Gopals Krishna et al., 2013). These small elements have their own individual behavior which can be outlined with a comparatively simple set of equations. The behaviors of these individual elements are then joined together to build the behavior of the whole structure with a large set of equations. In order to validate the results of material selection accomplished by Analytical Hierarchy Process (AHP), finite element analysis was performed using ANSYS software.

3.6.2 ANSYS Software

ANSYS is a finite element analysis software for exploring the performance of processes or products in a virtual reality (S V Gopals Krishna et al., 2013). This type of virtual reality product development is indicated as virtual prototyping. The users can simulate various structural analysis to optimize the product life. So when it comes to manufacturing, it can reduce the level of risk and the cost of invalid designs. ANSYS software provides the effects of design on the whole product behavior, such as strains, stresses and reaction forces.

3.6.3 Analysis using ANSYS Software

The finite element analysis simulation is carried out by modeling a car door panel with appropriate dimension specifications and selected properties in the first place (Patil et al., 2012). Then, the car door model will be subjected to various structural analysis for validation.

3.6.3.1 Solid Modeling

The car door panel is designed and modeled as a solid using CATIA software. The model was 700 mm in height with a cross section of 843 mm x 356.35 mm. The car door model was shown in Figure 3.5.

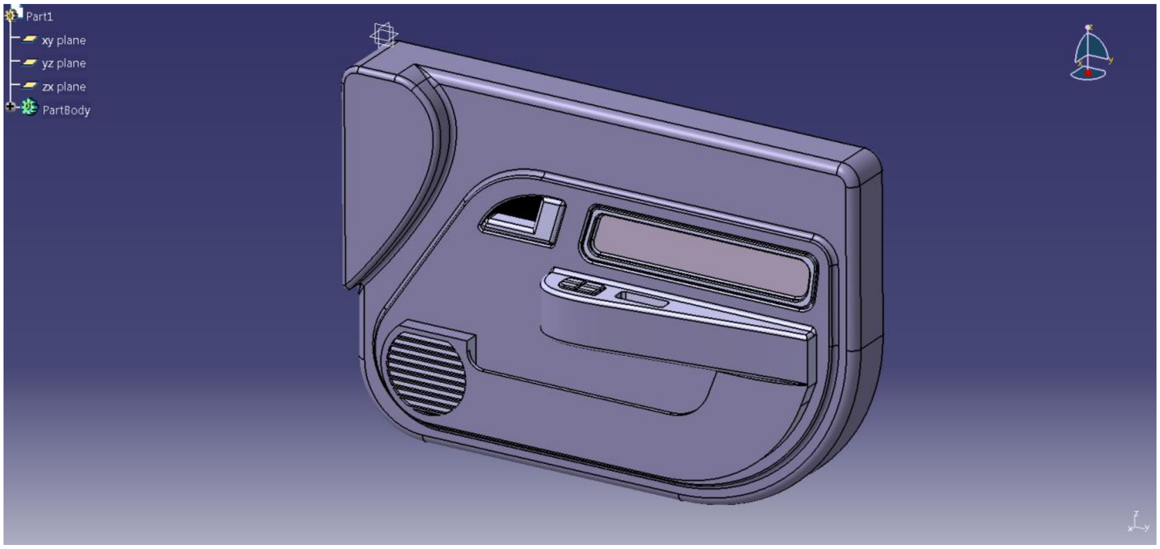


Figure 3.6: Car door panel designed using in Catia V5R21 software

3.6.3.2 Conventional material used

Conventional material used for car door panel is Acrylonitrile-Butadiene-Styrene (ABS). ABS is mainly be used for structural application because it is a low cost engineering plastic. The material properties of ABS is shown in Table 3.5.

Table 3.5: Material properties of conventional materials used

Material	Density (kg/m^3)	Tensile strength (MPa)	Young's modulus (GPa)	Poisson's ratio
ABS	1040	44	2.25	0.35

3.6.3.3 New material used

New composite material used for car door panel is kenaf fiber reinforced with PLA composites. Polylactic acid (PLA) resin with a diameter of 5 μm was used as the matrix whereas kenaf fiber bundles were used as the reinforcement. The dimension of reinforcement is approximately 50 to 150 μm in diameter and 500 mm in length. These kenaf fibers are at a fiber content of 40%.

In FEM analysis, material properties of material were required to simulate the mechanical behavior of the model made of these materials. Basic mechanical characteristics such as density, tensile strength and Young's modulus are shown in Table 3.6. The first step of static analysis started with entering the value of different material properties into ANSYS software.

Table 3.6: Material properties of new materials used

Material	Density (kg/m^3)	Tensile strength (MPa)	Young's modulus (GPa)	Poisson's ratio
PLA-Kenaf (40%)	1350	82	8	0.32

3.6.3.4 Meshing

After entering the values of different material properties, the second step is to import the assembled car door model to ANSYS workbench in STP format (Das 2015). In third step, the mesh is generated with selected material and structural properties which helps to define how the structure reacts to different loading conditions.

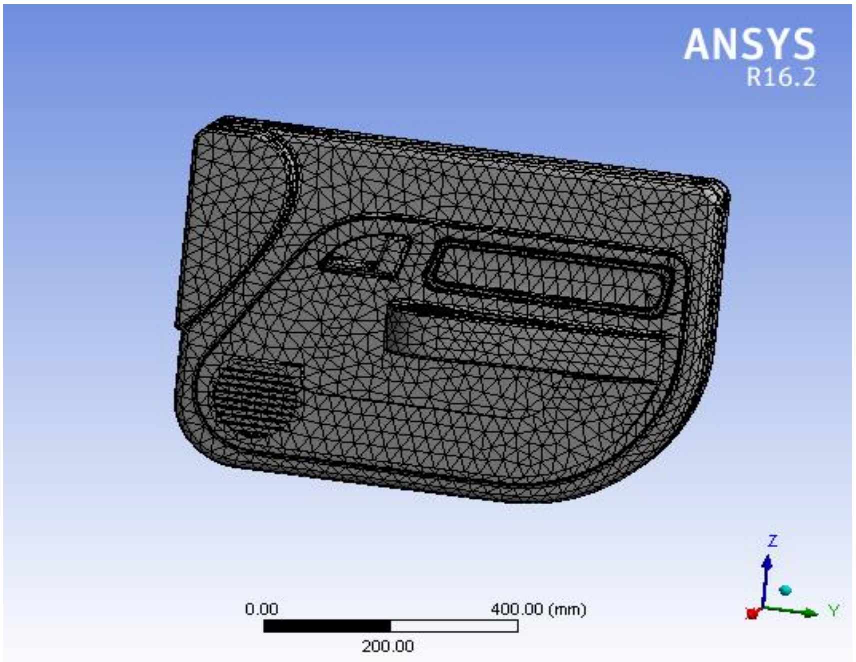


Figure 3.7: Meshed model of car door panel

3.6.3.5 Loads and Boundary Conditions

Next, nodes are allocated at certain density of the car door model by considering the anticipated stress levels of a specific area to analyze the model. The model is analyzed with static analysis under different loads and boundary conditions such as Total deformation, Equivalent stress and Maximum principal elastic strain. The selection of area at which motions are captured is significant while employing the boundary condition. To apply the load, the calculation of load is calculated as follows:

Input data (1): Car speed at 36 km/hour

$$Mass\ of\ the\ car = 1075\ kg \tag{3.11}$$

$$Average\ mass\ of\ 5\ persons\ = 350\ kg \tag{3.12}$$

$$Total\ mass = Mass\ of\ the\ car + Average\ mass\ of\ 5\ persons \quad (3.13)$$
$$= 1075\ kg + 350\ kg$$
$$= 1425\ kg$$

$$Speed\ of\ the\ car = 36\ km/hour = 10\ m/s \quad (3.14)$$

Assume the car hits at another similar car and it will stop in 0.1 seconds.

$$Deceleration\ of\ the\ car = \frac{u-v}{t} = \frac{10-0}{0.1} = 100\ m/s^2 \quad (3.15)$$

where

u = initial velocity of the car in m/s

v = final velocity of the car in m/s

t = time when the vehicles stopped in seconds, s

$$Forced\ acted\ during\ collision, F = ma \quad (3.16)$$
$$= 1425\ kg \times 100\ m/s^2$$
$$= 142500\ N$$

where

m = mass of the car in kg

a = acceleration of the car in m/s^2

For the calculation of pressure, the force is converted into pressure, P which is acted upon the rear surface of the modeled car door panel.

$$Area\ of\ the\ rear\ face\ of\ car\ door\ panel, A = l \times b \quad (3.17)$$
$$= 843\ mm \times 356.35\ mm$$
$$= 300403.05\ mm^2$$
$$= 0.30040305\ m^2$$

where

l = length of rear face of car door panel in mm

b = breadth of rear face of car door panel in mm

$$Pressure\ acted\ upon\ car\ door\ panel, P = \frac{F}{A} \tag{3.18}$$

$$= \frac{142500\ N}{0.30040305\ m^2}$$

$$= 474362.69\ N/m^2$$

where

F = force acted during collision in N

A = area of the front face of car door panel in m^2

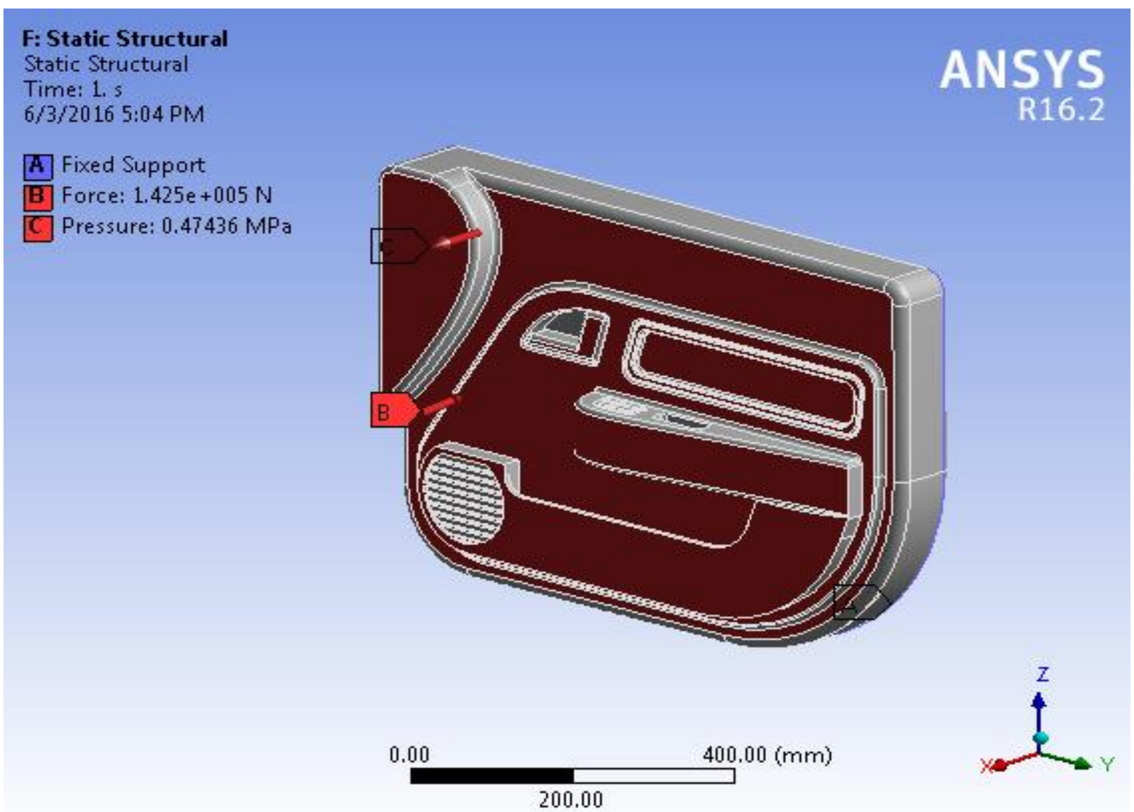


Figure 3.8: Boundary condition and load applied on the model when car speed is at 36 km/hour

Input data (2): Increase car speed to 72 km/hour

$$Mass\ of\ the\ car = 1075\ kg \tag{3.19}$$

$$Average\ mass\ of\ 5\ persons\ = 350\ kg \tag{3.20}$$

$$\begin{aligned} Total\ mass &= Mass\ of\ the\ car + Average\ mass\ of\ 5\ persons \\ &= 1075\ kg + 350\ kg \\ &= 1425\ kg \end{aligned} \tag{3.21}$$

$$Speed\ of\ the\ car = 72\ km/hour = 20\ m/s \tag{3.22}$$

Assume the car hits at another similar car and it will stop in 0.1 seconds.

$$Deceleration\ of\ the\ car = \frac{u-v}{t} = \frac{20-0}{0.1} = 200\ m/s^2 \tag{3.23}$$

where

u = initial velocity of the car in m/s

v = final velocity of the car in m/s

t = time when the vehicles stopped in seconds, s

$$\begin{aligned} Forced\ acted\ during\ collision, F &= ma \\ &= 1425\ kg \times 200\ m/s^2 \\ &= 285000\ N \end{aligned} \tag{3.24}$$

where

m = mass of the car in kg

a = acceleration of the car in m/s^2

For the calculation of pressure, the force is converted into pressure, P which is acted upon the rear surface of the modeled car door panel.

$$Area\ of\ the\ rear\ face\ of\ car\ door\ panel, A = l \times b \tag{3.25}$$
$$= 843\ mm \times 356.35\ mm$$
$$= 300403.05\ mm^2$$
$$= 0.30040305\ m^2$$

where

l = length of rear face of car door panel in mm

b = breadth of rear face of car door panel in mm

$$Pressure\ acted\ upon\ car\ door\ panel, P = \frac{F}{A} \tag{3.26}$$
$$= \frac{285000\ N}{0.30040305\ m^2}$$
$$= 948725.39\ N/m^2$$

where

F = force acted during collision in N

A = area of the front face of car door panel in m^2

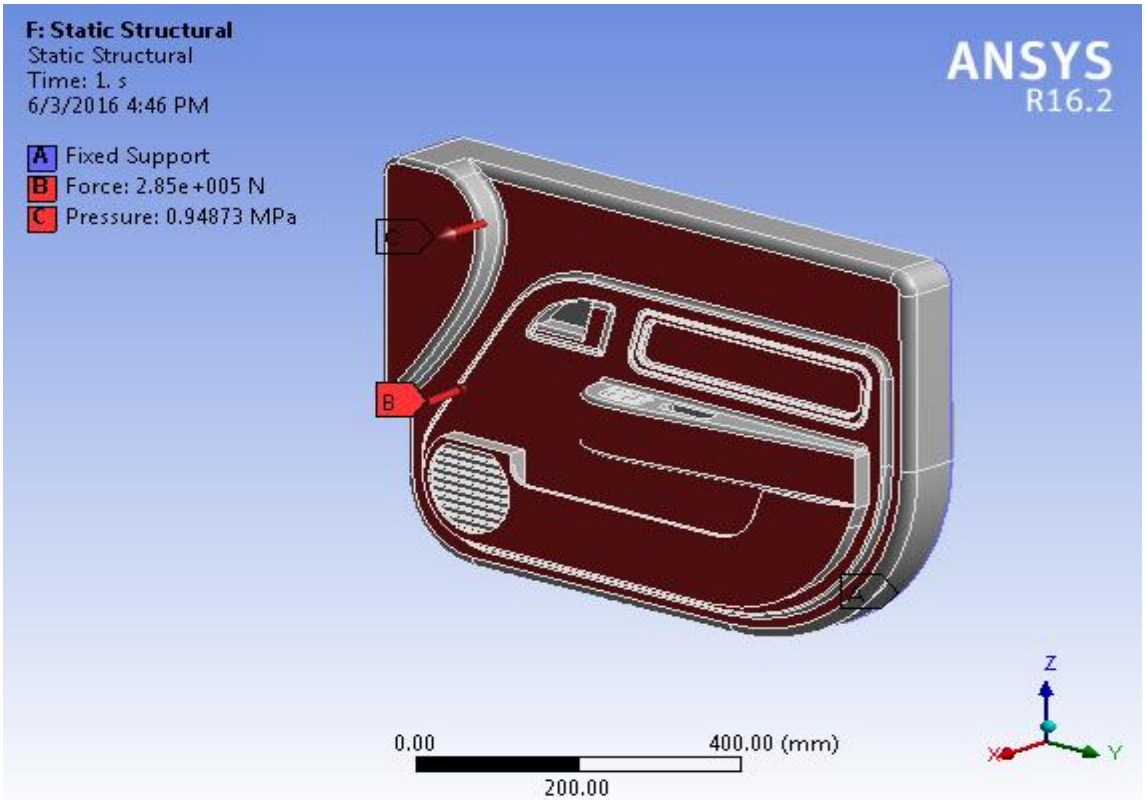


Figure 3.9: Boundary condition and load applied on the model when car speed has increased to 72 km/hour

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This section describes the results of the study that were carried out based on the methods as described in Chapter 3. It elaborates more on the findings gathered of this research. The raw data and complete results were labeled and tabulated orderly. Meanwhile, the results obtained throughout the software analysis and simulation were analyzed and interpreted. The results will be presented in three sections which includes Quality Function Deployment (QFD), Analytical Hierarchy Process (AHP) and Finite Element Analysis (AHP). In section one, Quality Function Deployment (QFD) identified the technical requirements of materials for car door panel by translating customer requirement to technical requirement. In section two, Analytical Hierarchy Process (AHP) method determines which alternative is the best material for car door panel. Lastly, in section three, Finite Element Analysis (FEA) determines and compares the strength of the conventional and new selected material for car door panel.

4.2 QUALITY FUNCTION DEPLOYMENT (QFD)

This research has proposed the integration of environmental consideration into Quality Function Deployment (QFD) method for the material design of car door panel. The five steps involved in building the house of quality was performed as follows.

Step 1: Identification of customer requirements (WHATs).

The first step in Quality Function Deployment (QFD) method has identified the customer needs. Because of the global issues we are facing today, the concern on environmental factors are increased. Hence, the identification of customer requirements were not only based on customer needs but also involved the environmental consideration. Based on the literature review in Chapter 2 on journals and e-books, several customer requirements on environmental aspects has been identified as illustrated in Table 4.1.

Table 4.1: Identification of customer requirements

No.	Customer Requirements
1	Lightweight
2	Performance
3	Low cost
4	Durability
5	Recycling and life cycle consideration

Step 2: Identification of technical requirements (HOWs).

The second step of the Quality Function Deployment (QFD) has identified technical requirements of material for car door panel. In this step, customer needs were translated into technical requirements that describe the customer needs in a technical language. These technical language was measurable and the results were able to control and compare with other aspects. Table 4.2 shows the technical requirements which have been technically translated from customer requirements.

Table 4.2: Identification of technical requirements

No.	Technical/ Design Requirements
1	Tensile strength (MPa)
2	Young's modulus (MPa)
3	Flexural strength (MPa)
4	Flexural modulus (MPa)
5	Density (gcm^{-3})
6	Impact strength (kJ/m^2)
7	Sustainability

Step 3: Develop a relationship matrix between customer requirements and technical requirements

In third step of the Quality Function Deployment (QFD) has compared the customer requirements with technical requirements and determined their relationship. The relationship between the customer requirement of lightweight and technical requirement of tensile strength has assigned with an important scale of 4 because lightweight is important for tensile strength. Besides, the relationship between customer requirement of lightweight and the technical requirement of density has assigned with a scale of 5 because lightweight is very important for density.

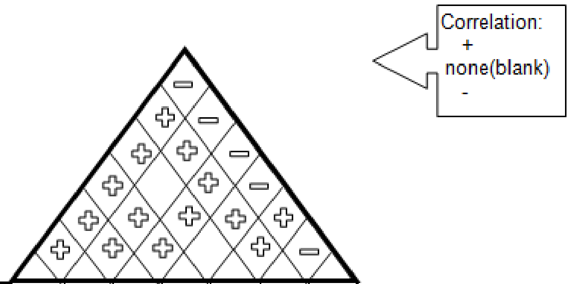
Other than that, the relationship between customer requirement of durability and the technical requirement of flexural strength has assigned with a scale of 2 because lightweight has low importance for flexural strength. The empty spaces indicated there is no relationship between the customer requirement and the technical requirement.

Table 4.3: Relationship matrix between customer requirements and technical requirements

Technical Requirements / Customer Requirements	**Importance**	Tensile strength	Young's modulus	Flexural strength	Flexural modulus	Density	Impact strength	Sustainability
Lightweight	5	4	4	3	3	5	2	2
Performance	5	5	5	5	5	2	5	
Low cost	3					2		3
Durability	4	2	2	2	2		2	4
Recycling and life cycle consideration	4							5

Step 4: Develop an interrelationship matrix between technical requirements.

In fourth step of the Quality Function Deployment (QFD) has identified the interrelationship between each of the technical requirements. The correlation between the technical requirements of tensile strength and impact strength was assigned with (+) sign because both of them are an intrinsic characteristics of a material. Moreover, the correlation between the technical requirements of tensile strength and sustainability was assigned with (-) sign because tensile strength would never affect sustainability. For the empty spaces, it indicated there is no relationship between these technical requirements, either positive or negative.



Technical Requirements / Customer Requirements	Importance	Tensile strength	Young's modulus	Flexural strength	Flexural modulus	Density	Impact strength	Sustainability
Lightweight	5	4	4	3	3	5	2	2
Performance	5	5	5	5	5	2	5	
Low cost	3					2		3
Durability	4	2	2	2	2		2	4
Recycling and life cycle consideration	4							5

Figure 4.1: Development of interrelationship matrix between technical requirement

Step 5: Develop prioritized technical requirement

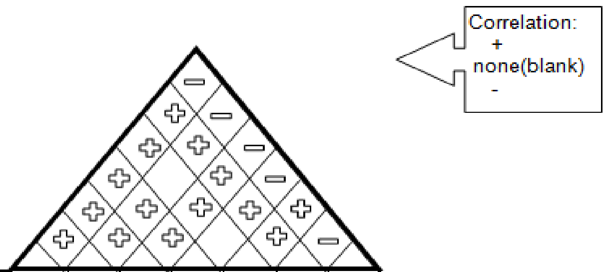
In fifth step of the Quality Function Deployment (QFD) has determined the absolute weight and relative weight for technical requirements.

For tensile strength, the absolute weight is expressed as in Eq. (4.1).

$$a_j = \sum_{i=1}^{n} R_{ij} c_i = (5 \times 4) + (5 \times 5) + (4 \times 2) = 53 \tag{4.1}$$

The relative weight for tensile strength is expressed as in Eq. (4.2).

$$b_j = {}^{a_j}\!/\!_{\sum a_j} = {}^{53}\!/\!_{53 + 53 + 48 + 48 + 41 + 43 + 55} = 0.16 \tag{4.2}$$



Technical Requirements / Customer Requirements	Importance	Tensile strength	Young's modulus	Flexural strength	Flexural modulus	Density	Impact strength	Sustainability
Lightweight	5	4	4	3	3	5	2	2
Performance	5	5	5	5	5	2	5	
Low cost	3					2		3
Durability	4	2	2	2	2		2	4
Recycling and life cycle consideration	4							5
Technical Importance: Absolute		53	53	48	48	41	43	55
Technical Importance: Relative		16%	16%	14%	14%	12%	13%	16%

Figure 4.2: House of Quality framework

4.3 ANALYTICAL HIERARCHY PROCESS (AHP)

The following research steps were performed using the steps that has been presented in previous chapter. Super Decision software was implemented to determine the selection of most appropriate material. Initially, the goal for selection is defined and then following by listed down the criteria and sub-criteria. After that, five alternatives materials are taken into consideration for material selection. Once the hierarchical model is identified, the main goal, criteria, sub-criteria and alternatives were entered to Super Decision software to develop a hierarchy framework and then analyze the selection of the most optimum material.

4.3.1 Developing AHP hierarchy framework

AHP hierarchy model was framed by using Super Decision software in Figure 4.3. The model started with the goal, criteria, sub-criteria and alternatives respectively. Each node in a level is the parent of every node in the next level. The parent node in the level was connected only to their pair-wise children nodes in the next level.

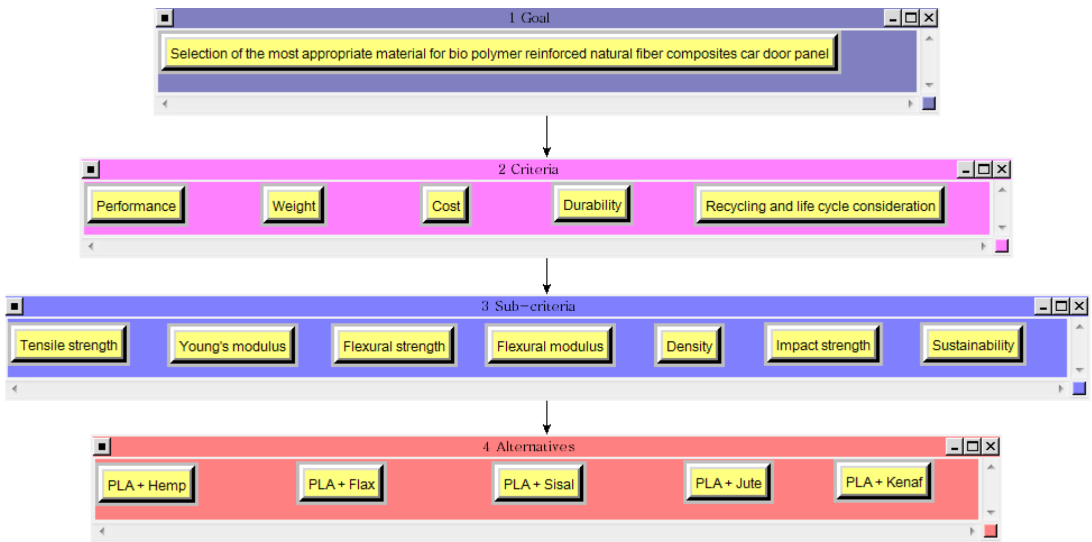


Figure 4.3: AHP hierarchy framework

4.3.2 Construct and perform judgment of pair-wise comparison

The pair-wise comparison was performed between the criteria with respect to main goal and then between sub-criteria with respect to criteria, and lastly between all the alternatives with respect to sub-criteria. One of the advantages of using Super Decision software is that it can derive accurate ratio scale priorities. This is as opposed to using traditional approaches because traditional approaches use assigning weights which lead to difficulties in justifying pair-wise comparison.

Figure below compares the importance of main criteria with respect to main goal. The pair-wise comparison process was obtained by answering the questionnaire generated by the Super Decision software as shown in Figure 4.4. The pair-wise questionnaire was conducted by referring to the importance of customer requirements in the House of Quality. This pair-wise judgment was determined by assigning a rating scale of 1 to 9. As an example, for the pair-wise between cost and durability with respect to the goal, it was assigned with a scale of 2. This means that the cost is two times as important than durability when selecting the material for car door panel.

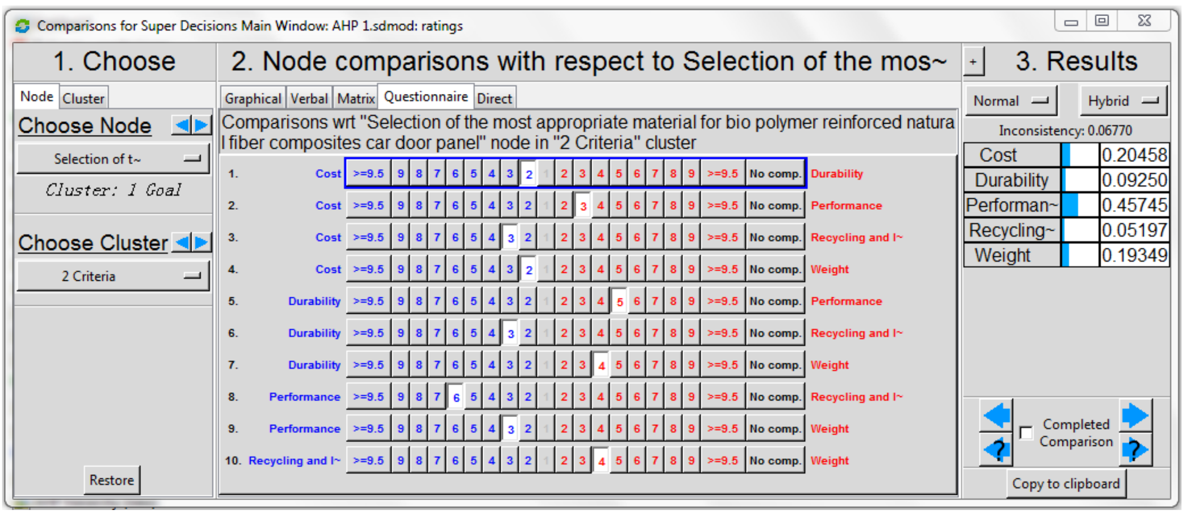


Figure 4.4: Pair-wise comparison through questionnaire of main criteria with respect to main goal

After performing pair-wise questionnaire, the results in questionnaire mode was automatically transformed into a matrix judgment scale. Based on the comparison with respect to the main goal, it shows the relative importance between cost and durability was in a matrix of 2.0. Meanwhile, the inconsistency ratio value has found to be 0.06770 which was within the suggested inconsistency ratio value of less than 0.10.

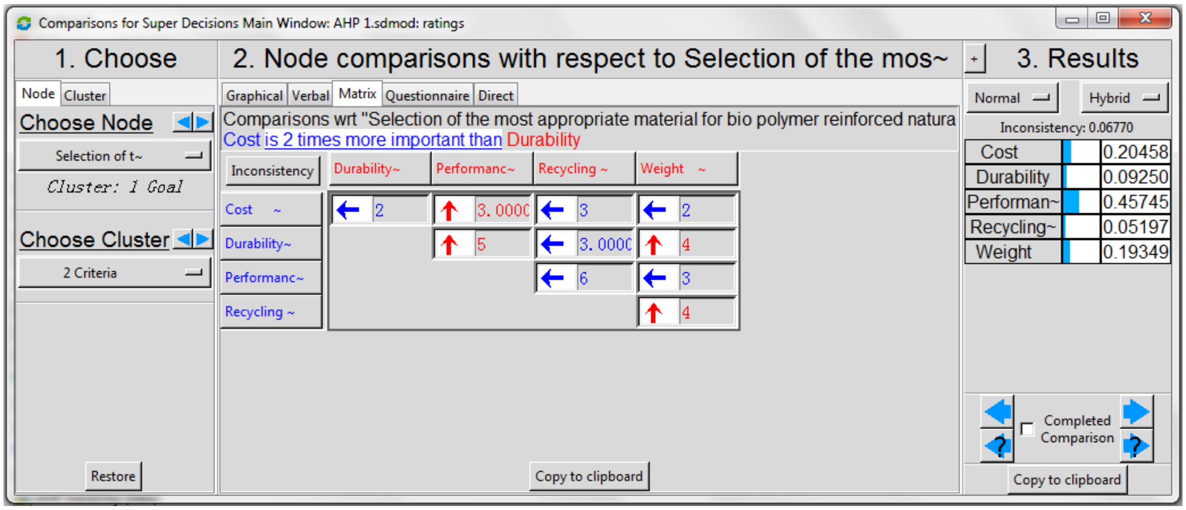


Figure 4.5: Pair-wise comparison matrix of main criteria with respect to main goal

In addition, figures below show the results of pair-wise comparison between main criteria and sub-criteria. In Figure 4.6, the pair-wise has compared the importance of sub-criteria with respect to one of the main criteria, Performance. The pair-wise questionnaire was rated by referring to the results of relationship matrix between customer requirements and technical requirements which has been developed in the House of Quality. For instance, based on the relationship matrix with respect to performance in House of Quality, it shows that tensile strength, young's modulus, flexural strength, flexural modulus and impact strength is 2.5 times more important than density for the performance in car door panel. Therefore, a scale of 6 was assigned for the pair-wise between density to flexural modulus, flexural strength, impact strength, tensile strength and young's modulus.

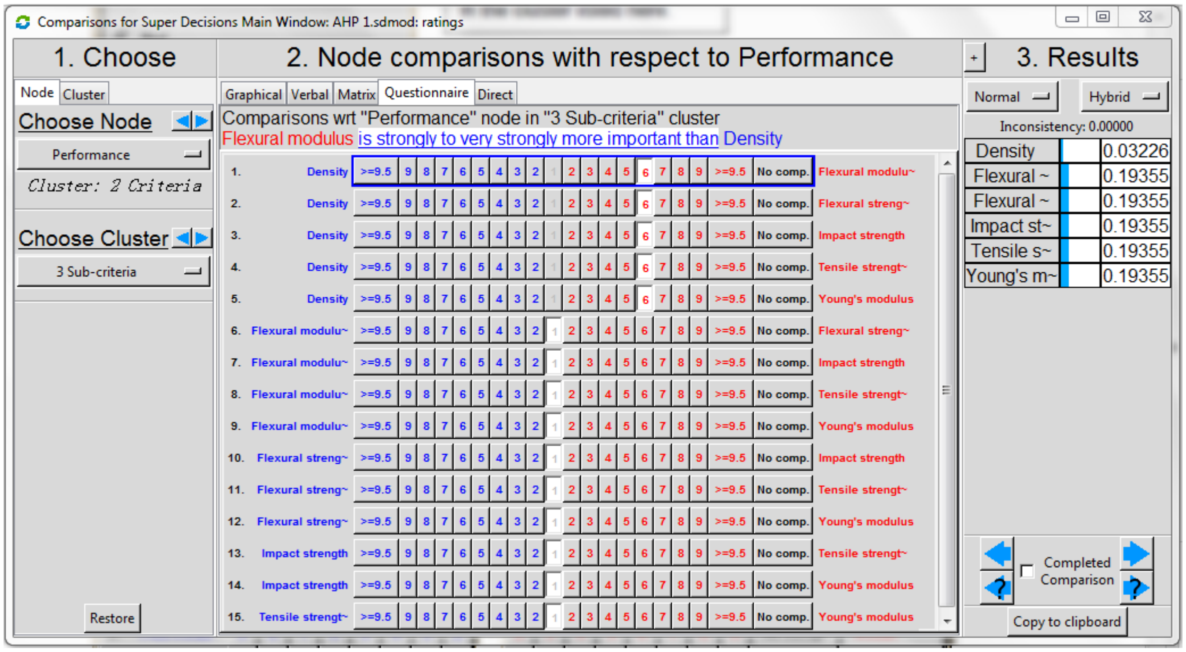


Figure 4.6: Pair-wise comparison through questionnaire of sub-criteria with respect to Performance

For the results in matrix mode, it shows the relative importance between density with flexural modulus, flexural strength, impact strength, tensile strength and young's modulus were in a matrix of 5.9999. The inconsistency ratio value has found to be 0 which means that there is no inconsistency in the node comparison with respect to performance.

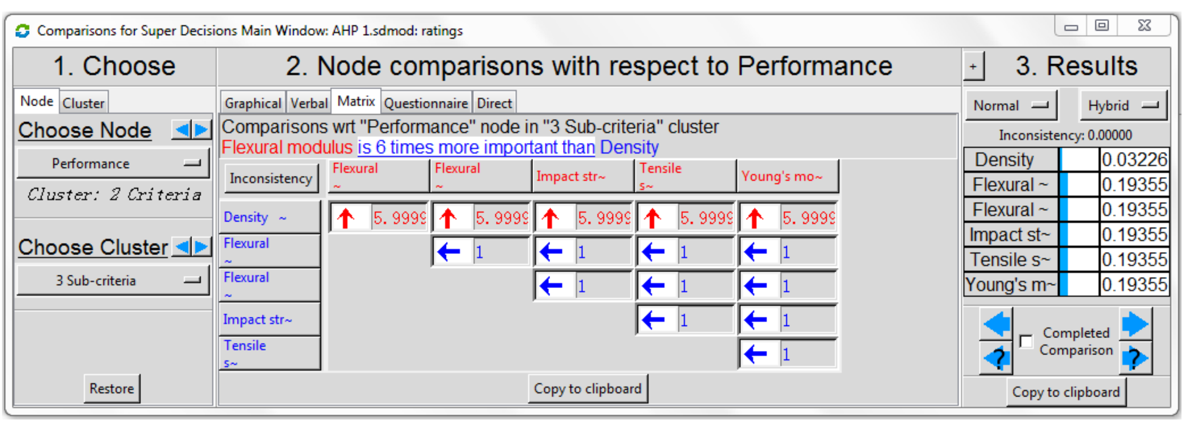


Figure 4.7: Pair-wise comparison matrix of sub-criteria with respect to Performance

Next, it shows the node comparisons with respect to Weight in Figure 4.8. The pair-wise questionnaire was also obtained by referring to the results of relationship matrix between customer requirements and technical requirements in the House of Quality. For example, since density was 1.67 times more important than flexural modulus, it was assigned with a scale of 4 at the dominant side. This means that the density is moderately to strongly more important than flexural modulus when considering the weight of the material.

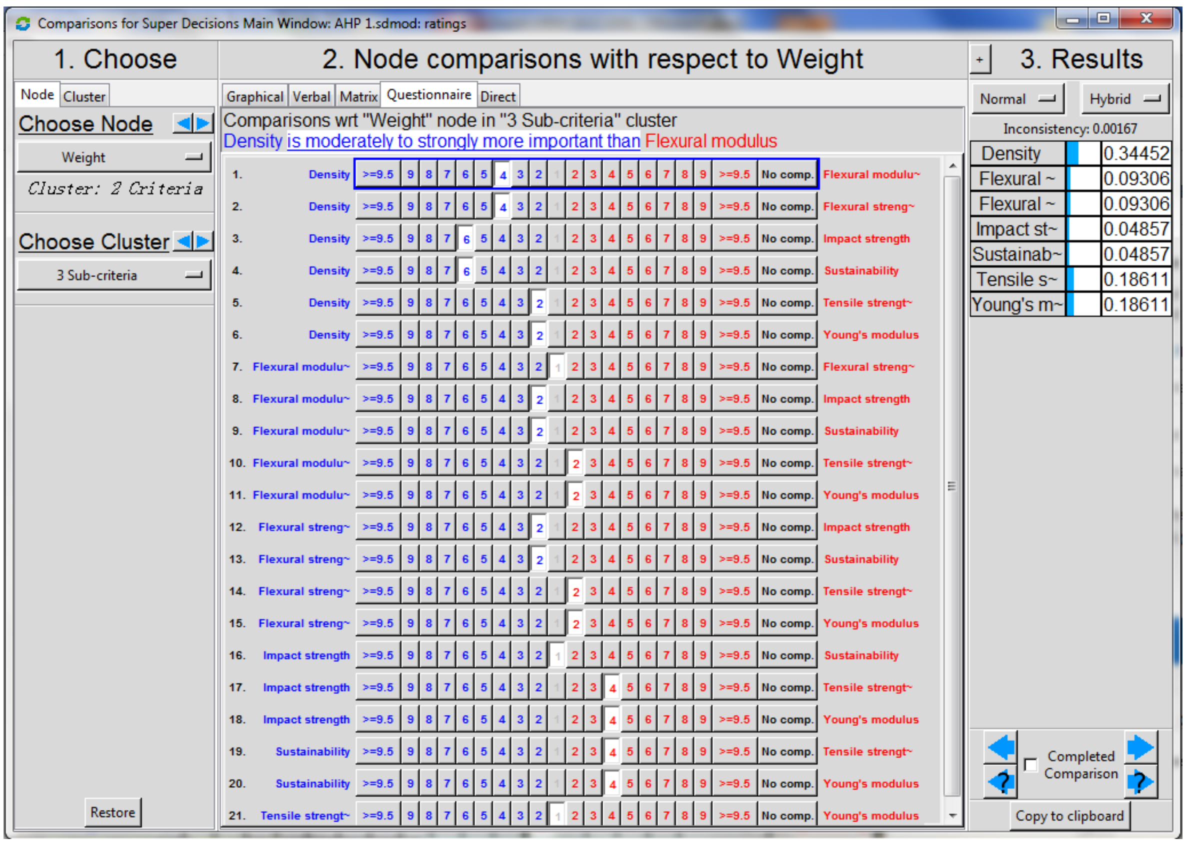


Figure 4.8: Pair-wise comparison through questionnaire of sub-criteria with respect to Weight

For the results in matrix mode, it shows the relative importance between density and flexural modulus was in a matrix of 5.9999. In this case, the density is 4 times more important than flexural modulus. Besides, the inconsistency ratio value has found to be 0.00167. It was within the suggested inconsistency ratio value of less than 0.10.

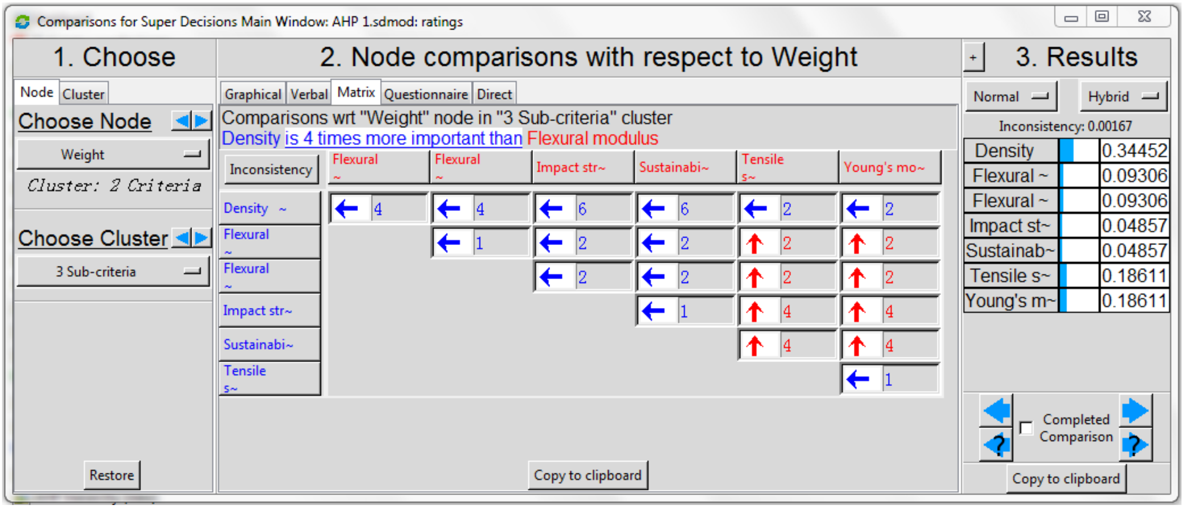


Figure 4.9: Pair-wise comparison matrix of sub-criteria with respect to Weight

Moreover, it shows the node comparisons with respect to Cost in Figure 4.10. The pair-wise questionnaire was also carried out by referring to the results of relationship matrix between customer requirements and technical requirements in the House of Quality. When considering the cost, sustainability was 1.5 times more important than density. Thus, it was assigned with a scale of 4 at sustainability side. In this case, sustainability is moderately to strongly more important than density when considering the cost of the material.

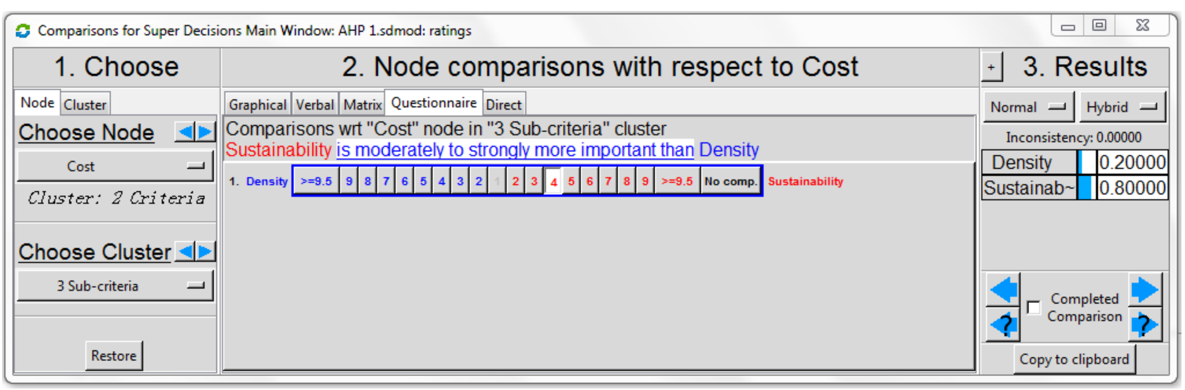


Figure 4.10: Pair-wise comparison through questionnaire of sub-criteria with respect to Cost

For the results in matrix mode, it shows the relative importance between density and sustainability was in a matrix of 4. In this situation, the sustainability is 4 times more important than density. Regarding to the inconsistency ratio, the pair-wise with respect to cost is very consistent.

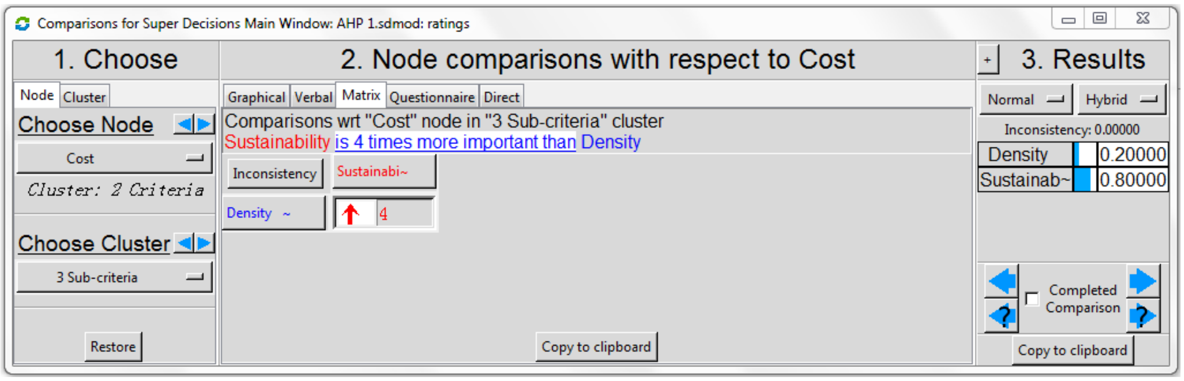


Figure 4.11: Pair-wise comparison matrix of sub-criteria with respect to Cost

In the next comparison, it shows the pair-wise comparisons with respect to Durability in Figure 4.12. In this comparison, the results of relationship matrix between customer requirements and technical requirements in the House of Quality was used as the reference for pair-wise questionnaire. When considering the durability of the material for car door panel, flexural modulus is equally as important as flexural strength. Thus, a scale of 1 was assigned in between of both side.

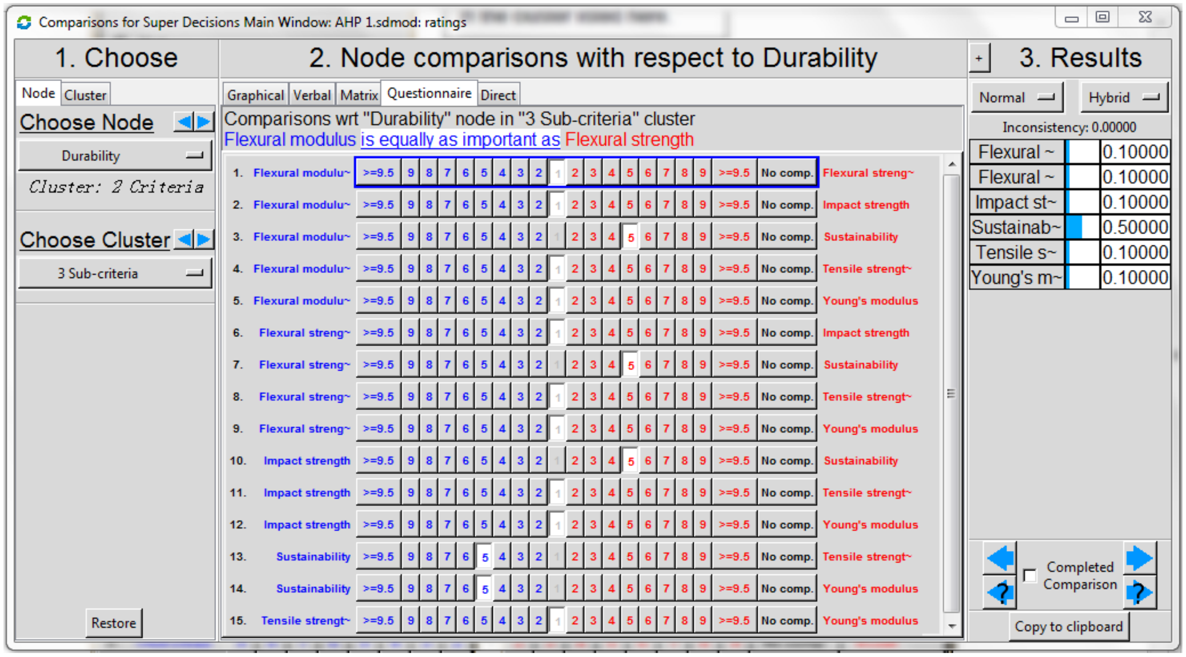


Figure 4.12: Pair-wise comparison through questionnaire of sub-criteria with respect to Durability

For matrix mode results, it shows the relative importance between flexural modulus and flexural strength was in a matrix of 1. In this instance, flexural modulus is 1 times more important than flexural strength. In relation to the inconsistency ratio, the pair-wise comparisons with respect to durability is very consistent.

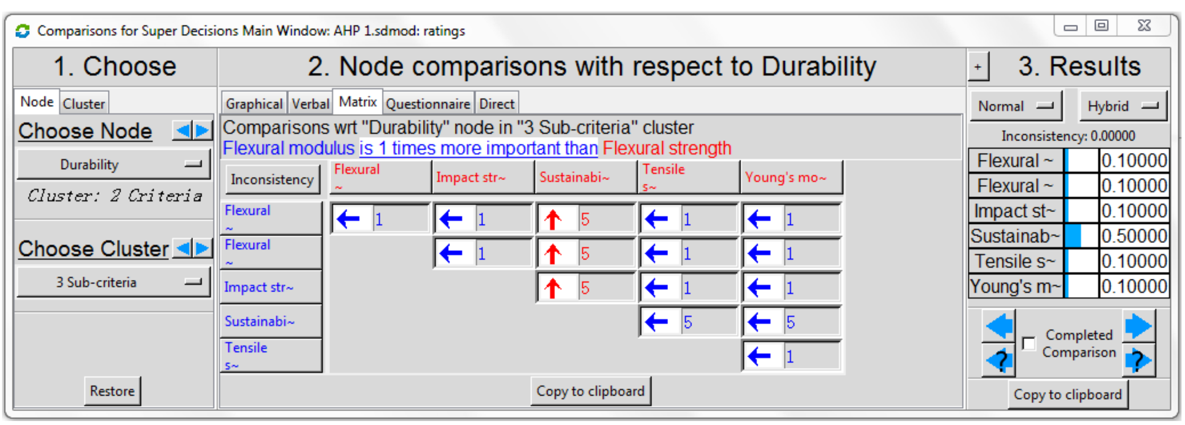


Figure 4.13: Pair-wise comparison matrix of sub-criteria with respect to Durability

The pair-wise comparison below compares the importance of alternative materials with respect to sub-criteria, Tensile strength. The pair-wise questionnaire was conducted by referring to the database of alternatives materials in Table 3.1 which has been collected in Chapter 3. As an example, for the pair-wise between PLA reinforced with flax and PLA reinforced with hemp with respect to tensile strength, the tensile strength of PLA reinforced flax is 55MPa whereas tensile strength of PLA reinforced hemp is 77MPa. Thus, PLA reinforced hemp was 1.4 times more important than PLA reinforced flax, it was assigned with a scale of 5 in the dominant side. In this case, PLA reinforced with hemp is strongly more important than PLA reinforced with flax when considering tensile strength of material for car door panel.

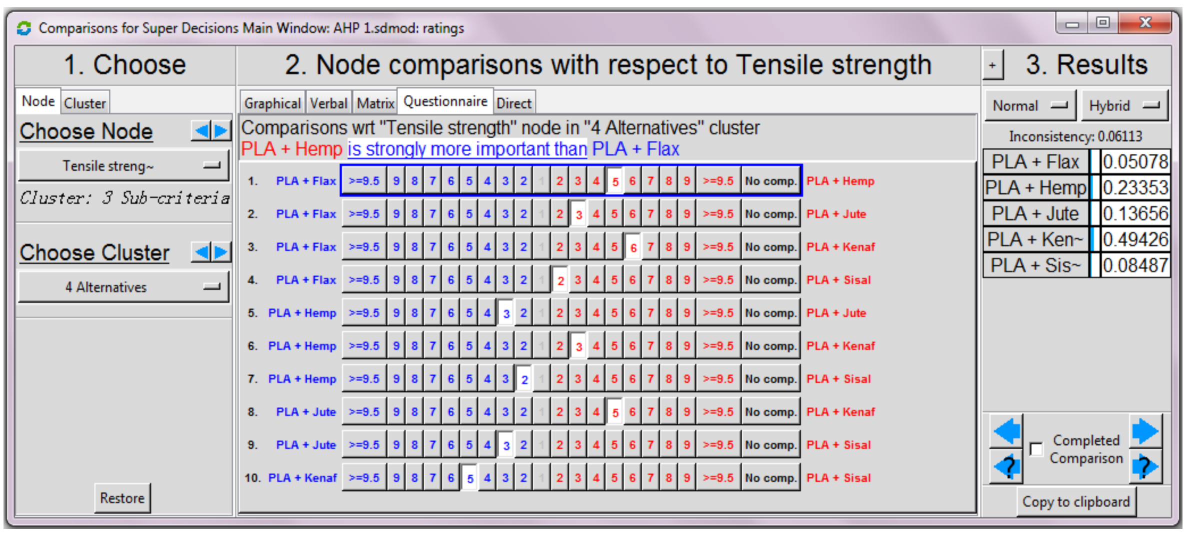


Figure 4.14: Pair-wise comparison through questionnaire of candidate materials with respect to Tensile strength

In Figure 4.15, the matrix results shows PLA reinforced with hemp is 5 times more important than PLA reinforced with flax with respect to tensile strength. Meanwhile, the inconsistency ratio value was 0.06113, it has found to be within the suggested inconsistency ratio value of less than 0.10.

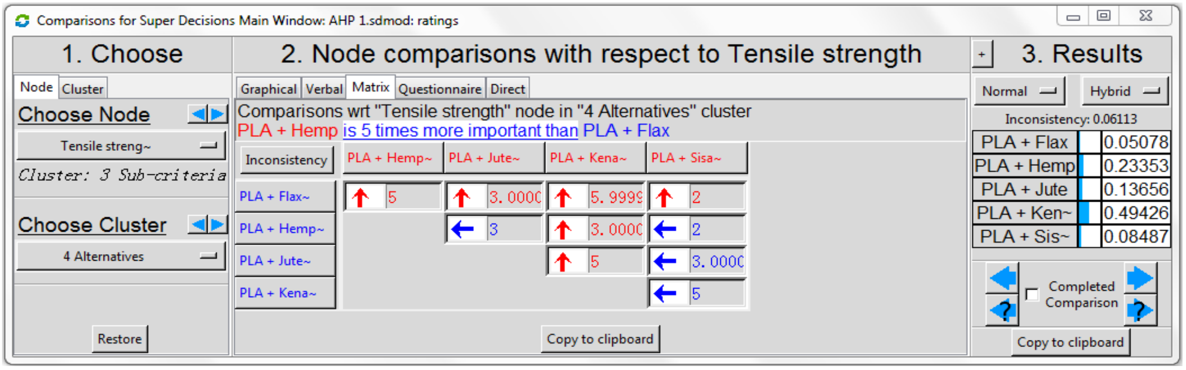


Figure 4.15: Pair-wise comparison of candidate materials with respect to Tensile strength

Next, the node comparisons with respect to Young's modulus was shown in Figure 4.16. The pair-wise questionnaire was conducted by referring to the material properties of alternatives materials. For instance, by referring to young's modulus of alternatives materials, PLA reinforced flax has a young's modulus of 6.31GPa whereas PLA reinforced hemp is 10GPa. It shows PLA reinforced hemp was 1.5 times more important than PLA reinforced flax. Thus, it was assigned with a scale of 4 in the side of PLA reinforced hemp. In this instance, PLA reinforced with hemp is moderately to strongly more important than PLA reinforced with flax when considering young's modulus of material for car door panel.

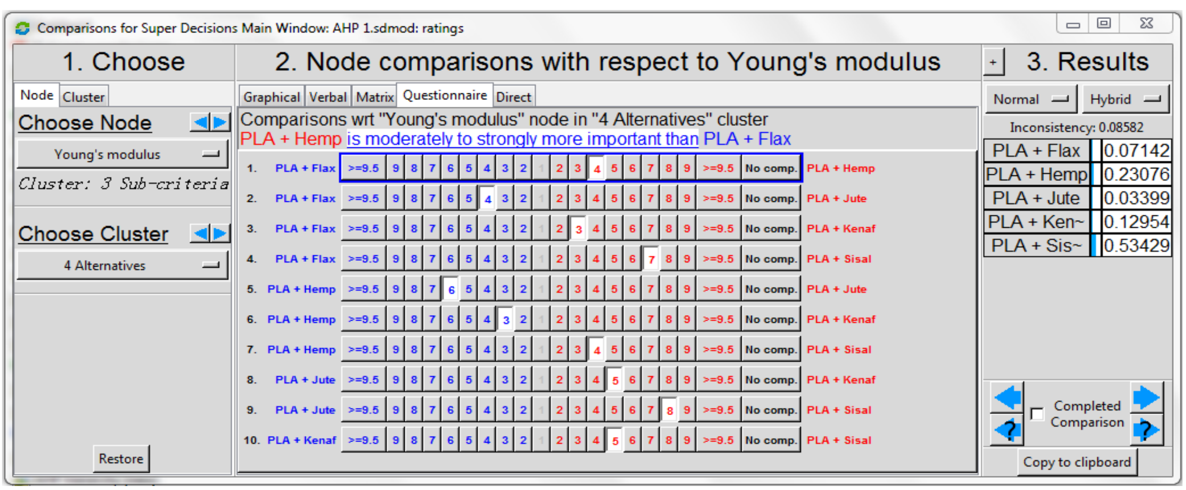


Figure 4.16: Pair-wise comparison through questionnaire of candidate materials with respect to Young's modulus

In Figure 4.17, the matrix results shows PLA reinforced with hemp is 4 times more important than PLA reinforced with flax with respect to young's modulus. The inconsistency ratio value was 0.08582, it has found to be within the suggested inconsistency ratio value of less than 0.10.

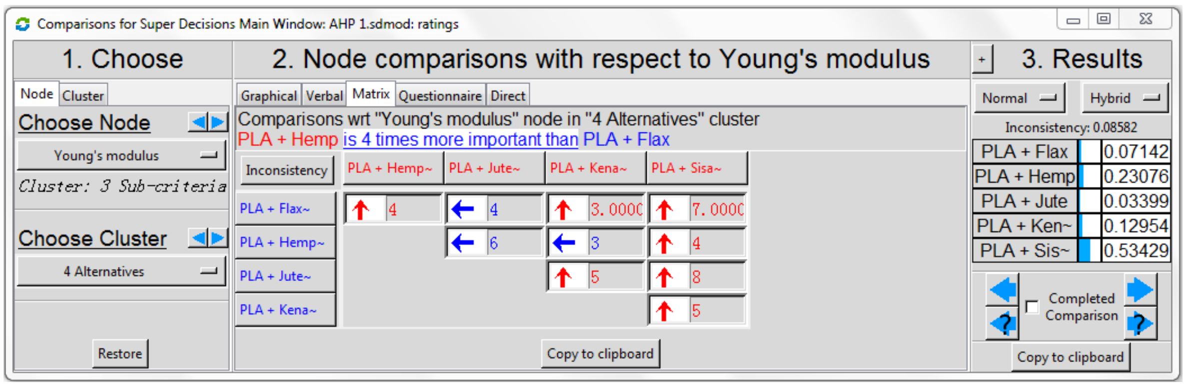


Figure 4.17: Pair-wise comparison of candidate materials with respect to Young's modulus

For the next pair-wise comparison, it shows the node comparisons with respect to Flexural strength in Figure 4.18. The pair-wise questionnaire was also carried out by referring to the material properties of alternatives bio composite materials in Table 3.1. For the flexural strength of alternatives materials, PLA reinforced flax is 65.6MPa while PLA reinforced hemp is 102MPa. It shows PLA reinforced hemp was 1.4 times more important than PLA reinforced flax. Therefore, it was assigned with a scale of 5 in the side of PLA reinforced hemp. In this case, PLA reinforced with hemp is strongly more important than PLA reinforced with flax when considering flexural strength of material for car door panel.

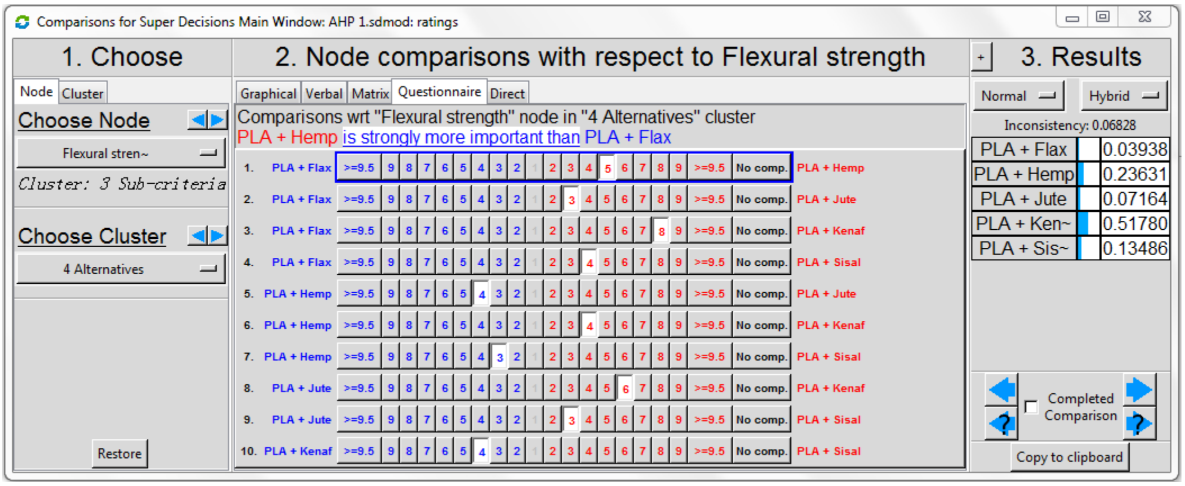


Figure 4.18: Pair-wise comparison through questionnaire of candidate materials with respect to Flexural strength

In Figure 4.19, the matrix results shows PLA reinforced with hemp is 5 times more important than PLA reinforced with flax with respect to flexural strength. The inconsistency ratio value was 0.06828, it has found to be within the suggested inconsistency ratio value of less than 0.10.

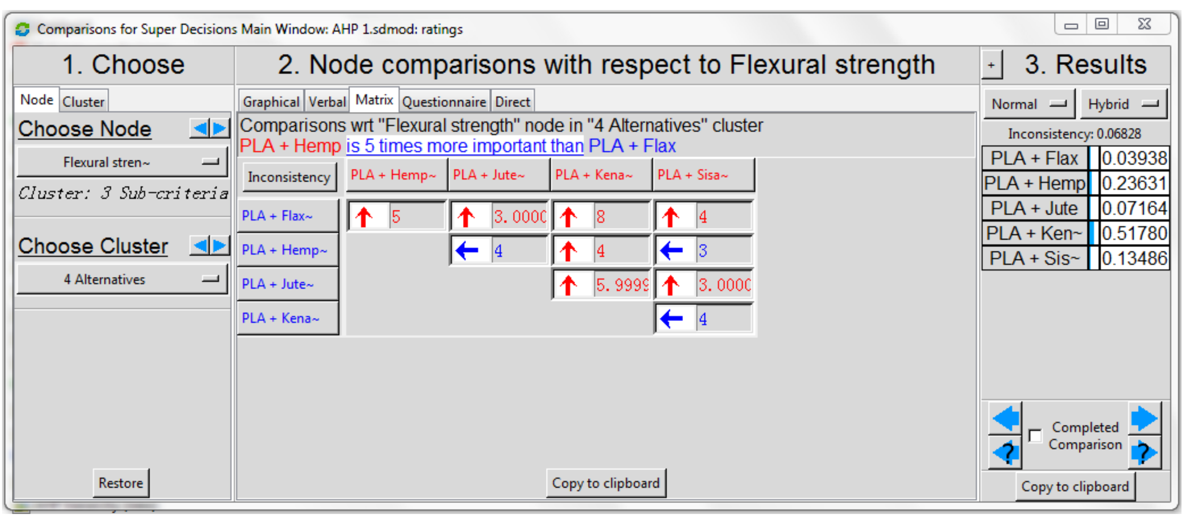


Figure 4.19: Pair-wise comparison of candidate materials with respect to Flexural strength

Moreover, it shows the pair-wise comparisons with respect to Flexural modulus in Figure 4.20. The pair-wise questionnaire was also conducted by referring to the material properties of alternatives bio composite materials in Table 3.1. According to the material properties, the flexural modulus of PLA reinforced flax is 3.6GPa whereas PLA reinforced hemp is 5.78GPa. In this case, PLA reinforced hemp was 1.6 times more important than PLA reinforced flax. Therefore, it was assigned with a scale of 3 in the side of PLA reinforced hemp. In this case, PLA reinforced with hemp is strongly more important than PLA reinforced with flax when considering flexural modulus of material for car door panel.

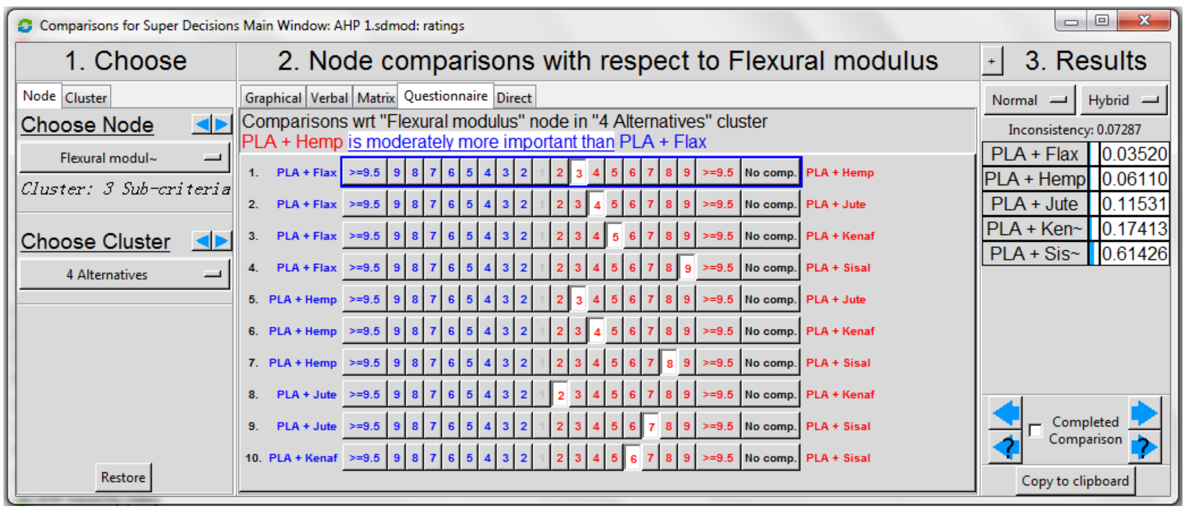


Figure 4.20: Pair-wise comparison through questionnaire of candidate materials with respect to Flexural modulus

For the results in matrix mode, it shows the relative importance between PLA reinforced hemp and PLA reinforced flax was in a matrix of 3. In this situation, PLA reinforced hemp is 3 times more important than PLA reinforced flax. Regarding to the inconsistency ratio, the inconsistency ratio value has found to be 0.07287 which was within the suggested inconsistency ratio value of less than 0.10.

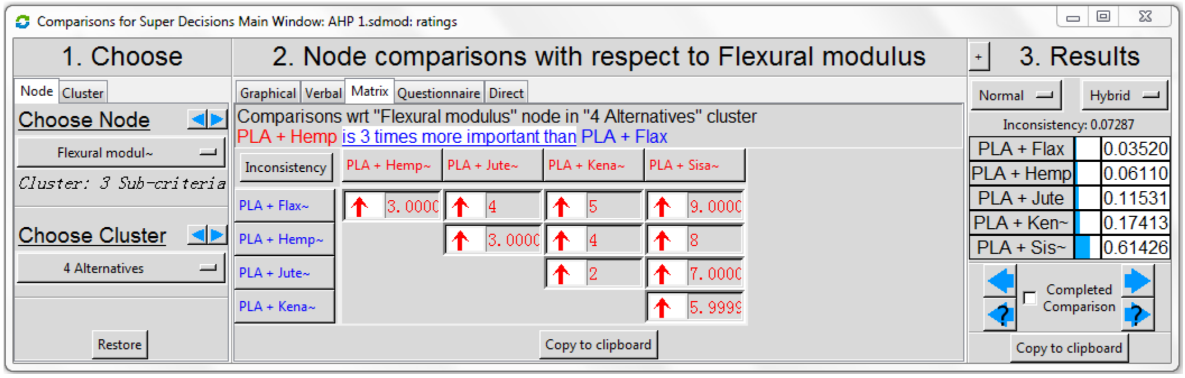


Figure 4.21: Pair-wise comparison of candidate materials with respect to Flexural modulus

Furthermore, the node comparisons with respect to Density was shown in Figure 4.22. The pair-wise questionnaire was conducted by referring to the material properties of alternatives bio composite materials. Based on the density of alternatives materials, PLA reinforced flax has a density of 1300 kg/m^3 whereas PLA reinforced hemp has a density of 1020 kg/m^3. In order to obtain the purpose of lightweight, it shows PLA reinforced hemp was 1.3 times more important than PLA reinforced flax. Thus, it was assigned with a scale of 3 in the side of PLA reinforced hemp. In this instance, PLA reinforced with hemp is moderately more important than PLA reinforced with flax.

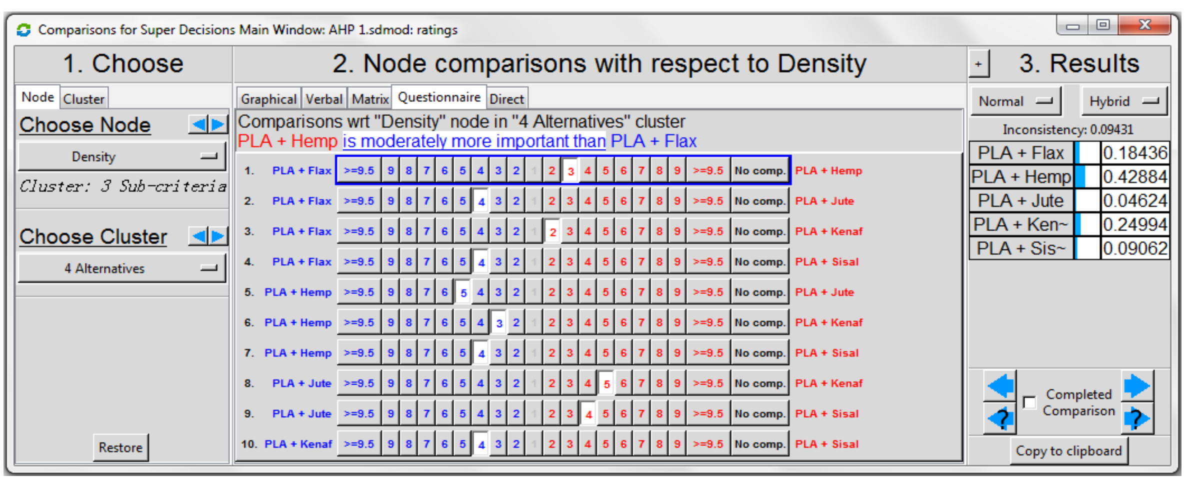


Figure 4.22: Pair-wise comparison through questionnaire of candidate materials with respect to Density

For the results in matrix mode, it shows the relative importance between PLA reinforced hemp and PLA reinforced flax was in a matrix of 3. In this situation, PLA reinforced hemp is 3 times more important than PLA reinforced flax. Regarding to the inconsistency ratio, the inconsistency ratio value has found to be 0.09431 which was within the suggested inconsistency ratio value of less than 0.10.

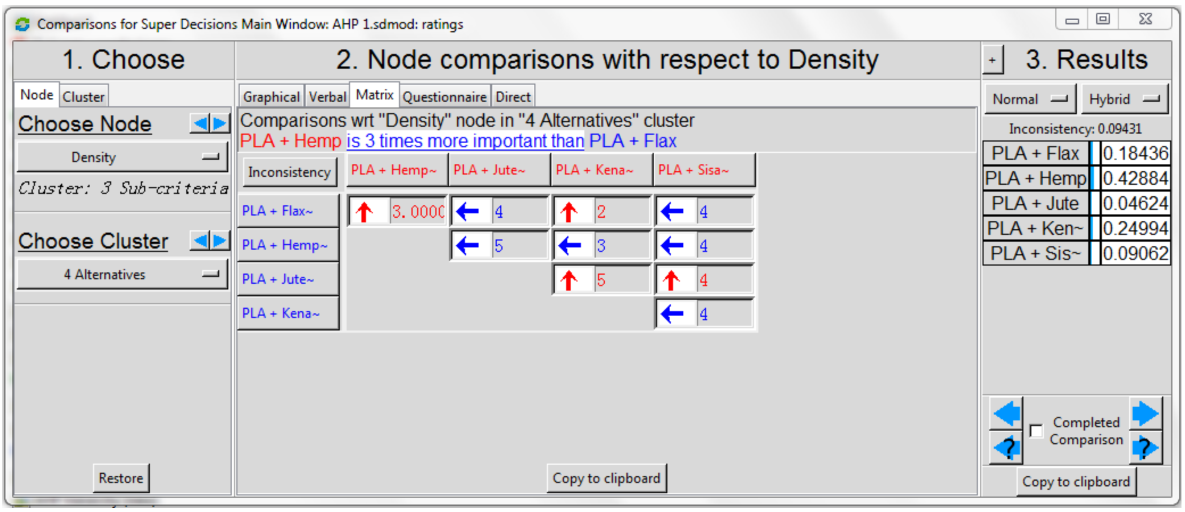


Figure 4.23: Pair-wise comparison of candidate materials with respect to Density

Additionally, figure below has compared the importance of alternatives materials with respect to impact strength. The material properties of alternatives materials in Table 3.1 was used as the reference for pair-wise questionnaire. According to the material properties of alternatives materials, PLA reinforced flax has an impact strength of 69 kJ/m^3 whereas PLA reinforced hemp has an impact strength of 19 kg/m^3. Here, it shows that PLA reinforced flax is 3.6 times more important than PLA reinforced hemp for the impact strength of materials in car door panel. Therefore, a scale of 4 was assigned for PLA reinforced flax. In this situation, PLA reinforced flax is moderately to strongly more important than PLA reinforced hemp.

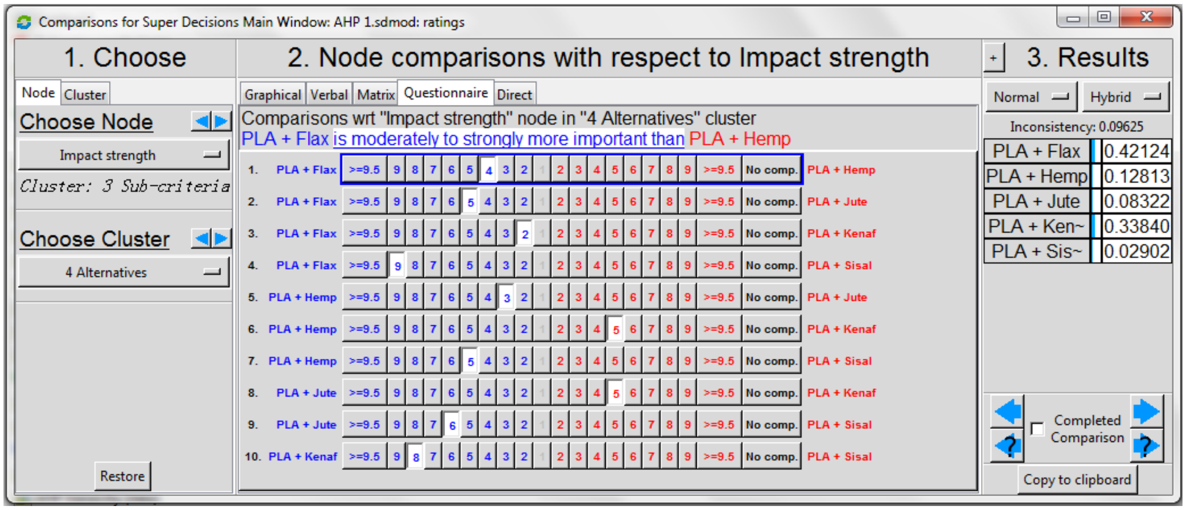


Figure 4.24: Pair-wise comparison through questionnaire of candidate materials with respect to Impact strength

For the results in matrix mode, it shows the relative importance between PLA reinforced flax and PLA reinforced hemp was in a matrix of 4. In other words, PLA reinforced hemp is 3 times more important than PLA reinforced flax. The inconsistency ratio value was 0.09625. It was within the suggested inconsistency ratio value of less than 0.10.

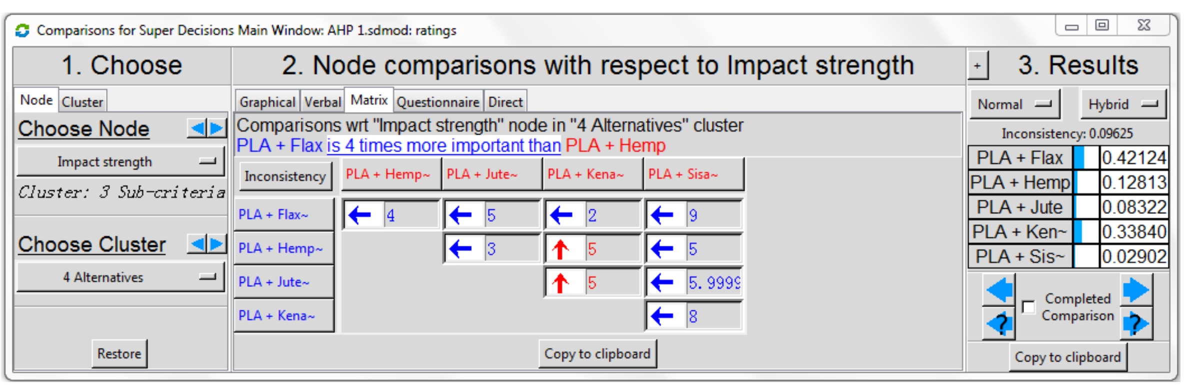


Figure 4.25: Pair-wise comparison of candidate materials with respect to Impact strength

Figure 4.26 shows the last node comparisons with respect to Sustainability to obtain high sustainability factor. In this respect, a scale of 3 was assigned in the side of PLA reinforced hemp because PLA reinforced hemp was 1.3 times more important than PLA reinforced flax. PLA reinforced hemp is moderately more important than PLA reinforced flax.

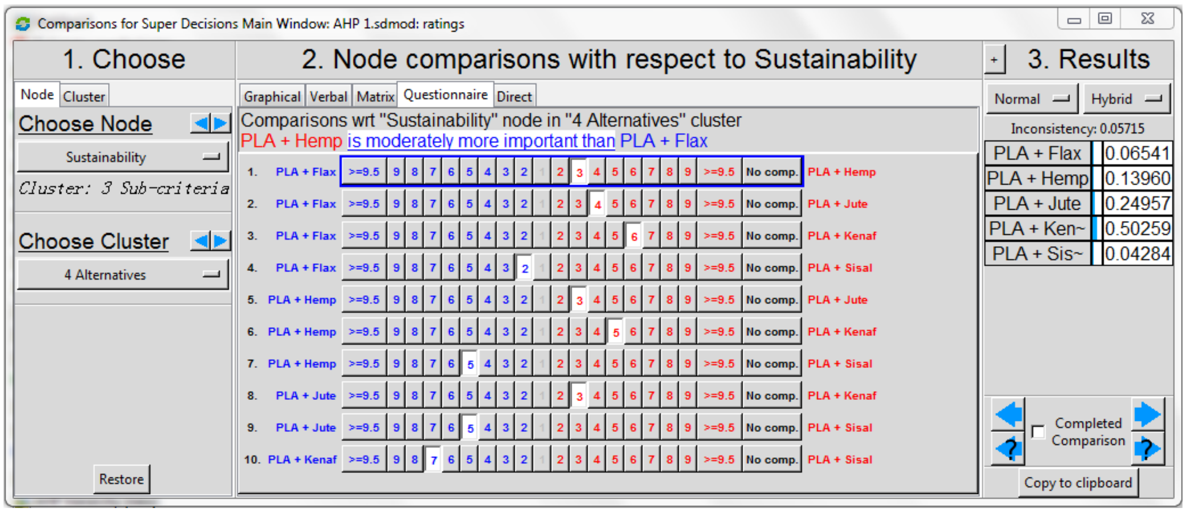


Figure 4.26: Pair-wise comparison through questionnaire of candidate materials with respect to Sustainability

For matrix mode results, it shows the relative importance between PLA reinforced flax and PLA reinforced hemp was in a matrix of 3. In this instance, PLA reinforced hemp is 3 times more important than PLA reinforced flax. In relation to the inconsistency ratio, the inconsistency ratio value has obtained 0.05715.

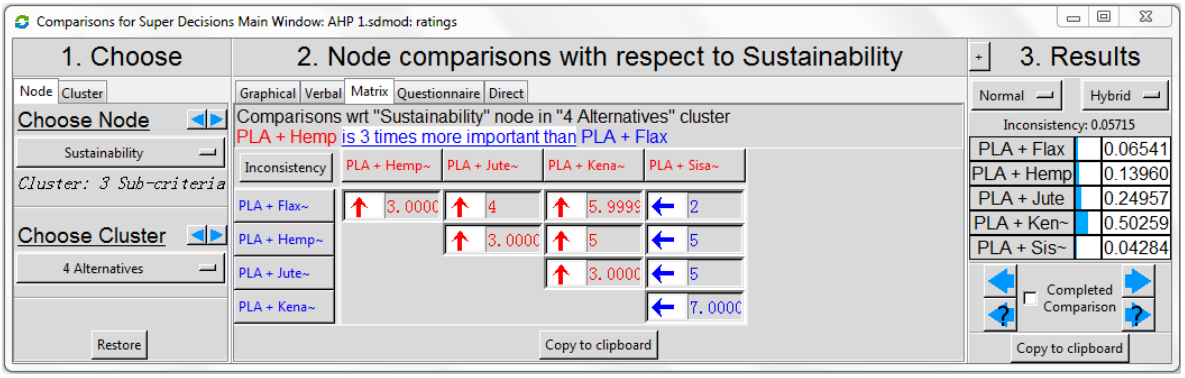


Figure 4.27: Pair-wise comparison of candidate materials with respect to Sustainability

4.3.3 Idea priority ranking

The overall material selection results obtained from AHP as shown in Figure 4.28 has revealed that PLA reinforced kenaf has the highest scores (0.412372), followed by PLA reinforced hemp (0.205436), PLA reinforced sisal (0.181595), PLA reinforced jute (0.102934) and PLA reinforce flax (0.097663). It can be seen that PLA reinforced with kenaf fiber is the most optimum composite material for car door panel as compared to other alternatives materials based on the highest priority ranking score.

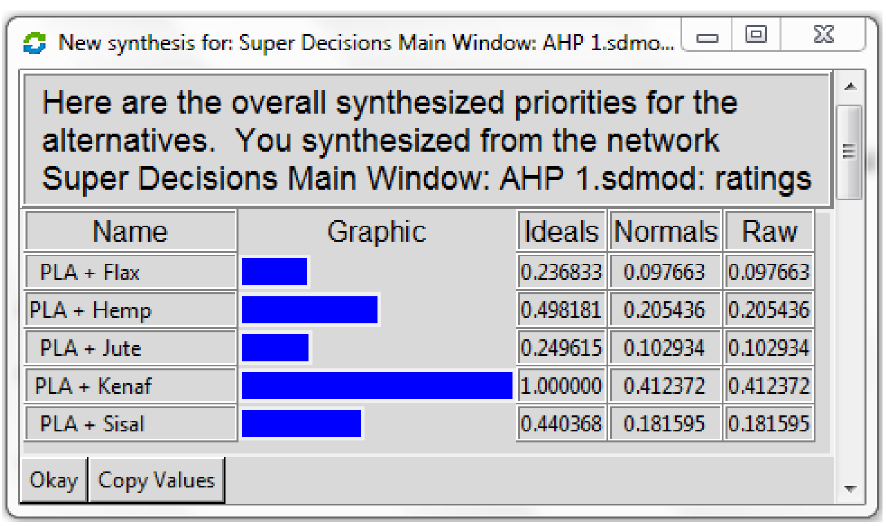


Figure 4.28: Overall synthesis results of AHP analysis for material selection

Based on Figure 4.28, there are three different types of results obtained from the simulated analysis. The *Normals* column shows the results in the form of priorities where it is usually uses to report on results. The Raw column is always read directly from the Supermatrix. The *Ideals* column is obtained from the *Normals* column by dividing each of its values by the largest value in the column.

For example, alternative PLA reinforced hemp scores 0.201812 in the simulated analysis, the Ideals results of PLA reinforced hemp can be obtained in Eq. (4.3).

$$Ideal\ result\ of\ PLA + Hemp = 0.201812/0.371206 \qquad (4.3)$$
$$= 0.543666$$

A complete results of total relative priority and alternative ranking with the corresponding aggregate weights was shown in Figure 4.29. PLA reinforced kenaf has found to be the most priority material for car door panel and the least priority material was PLA reinforced flax according to the ranking as illustrated in figure below.

Graphic	Alternatives	Total	Normal	Ideal	Ranking
	PLA + Flax	0.0977	0.0977	0.2368	5
	PLA + Hemp	0.2054	0.2054	0.4982	2
	PLA + Jute	0.1029	0.1029	0.2496	4
	PLA + Kenaf	0.4124	0.4124	1.0000	1
	PLA + Sisal	0.1816	0.1816	0.4404	3

Figure 4.29: Total relative priority and ranking of the five alternatives materials

4.3.4 Sensitivity Analysis

At the final stage, sensitivity analysis was performed to see how the ranking of alternative materials would change by changing the priority of the main criteria. Figure 4.30 demonstrates the sensitivity graph of the main criteria with respect to the main goal.

Based on the results, it is clearly to see that the results are favor in PLA reinforced kenaf. Hence, in this step it is important to see how would the choice of the most suitable material respond to any changes in the weights of the listed criteria.

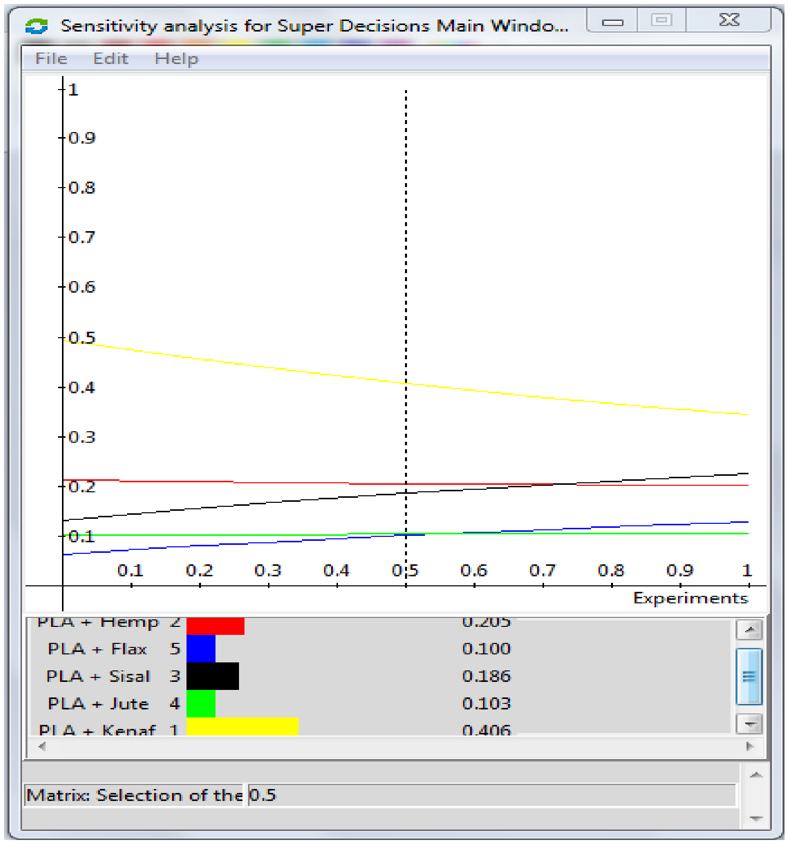
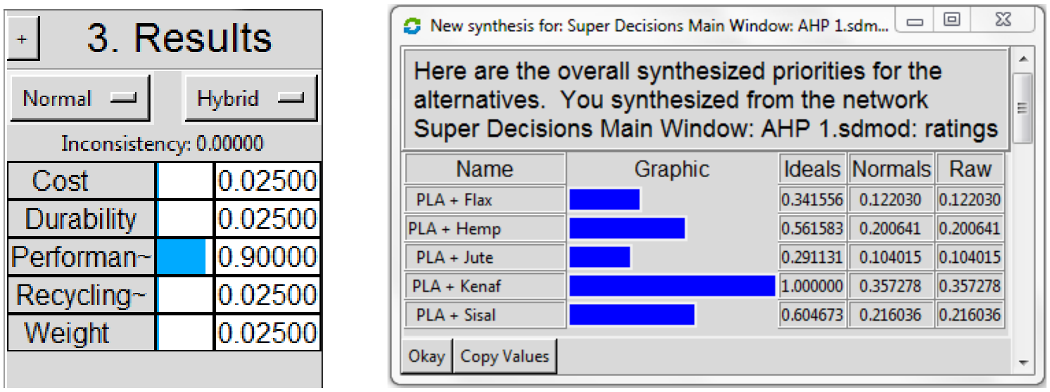


Figure 4.30: Material selection sensitivity graph for Performance

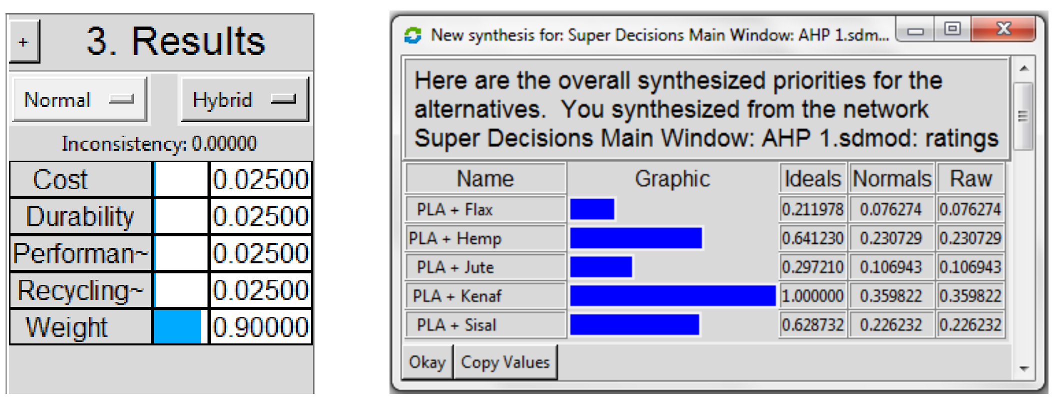
First, consider the performance of the material. By increasing the share of performance to 90% of the main goal and remaining 10% for other criteria, it has been observed that the best choice is still PLA reinforced sisal with a score of 35.7% as illustrated in Figure 4.31. This has proven that although the weight of performance was subjected to an unexpected change under normal condition, but the best choice is still remain the same and none of the alternatives has became dominant in the framework. The study was not sensitive to a small change in the weight of performance.



(a) (b)

Figure 4.31: Sensitivity analysis of Performance (a) the new assigned weight and (b) the priorities rating of the alternatives

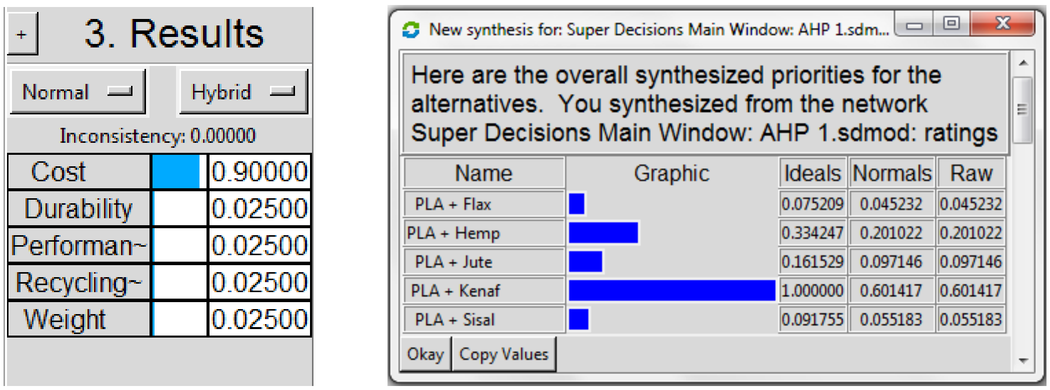
Next, consider the weight of the material. The weight factor was subjected to 90% and leaving 10% for other criteria to share equally. In this case, the same results of best choice is also PLA reinforced kenaf with a score of 35.98% as shown in Figure 4.32. The same conclusion can also be used for the weight criteria where this study was not sensitive to changes in the weight of cost.



(a) (b)

Figure 4.32: Sensitivity analysis of Weight (a) the new assigned weight and (b) the priorities rating of the alternatives

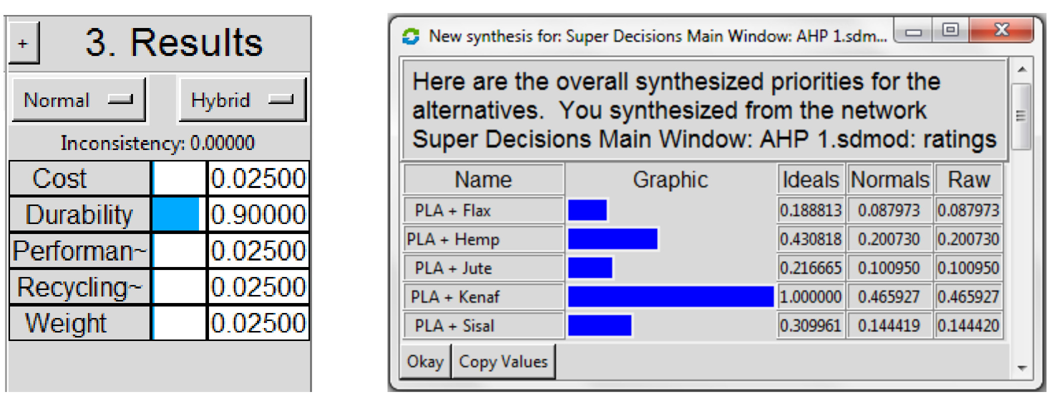
Moreover, for the cost of material. The same changes were also applied to see the effect on the choice of the best material. The weight of the cost factor was subjected to 90% and leaving 10% for other criteria to share equally. The results showed that PLA reinforced kenaf is also the most suitable material with a score of 60.1% as illustrated in Figure 4.33.



(a) (b)

Figure 4.33: Sensitivity analysis of Cost (a) the new assigned weight and (b) the priorities rating of the alternatives

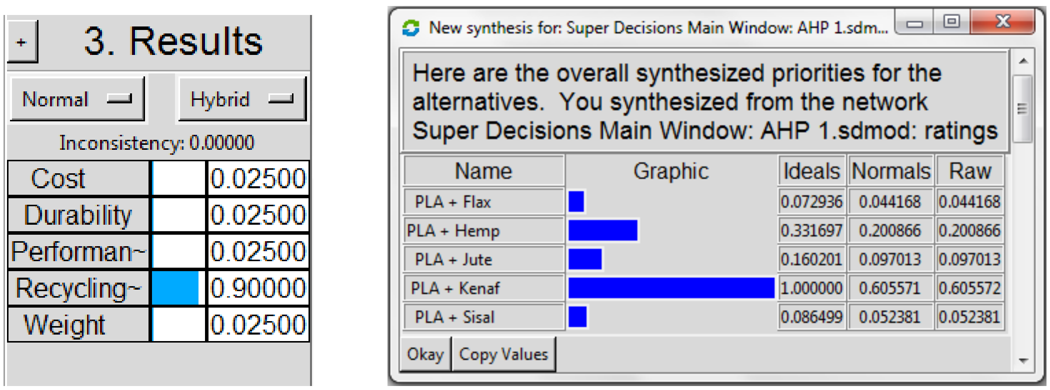
Besides, similar analysis was also performed for the durability factor. The weight of the durability factor was subjected to 90% and leaving 10% for other criteria to share equally. In this situation, the priorities results showed that PLA reinforced with kenaf remains as the best material choice as it scored 46.6% as shown in Figure 4.34.



(a) (b)

Figure 4.34: Sensitivity analysis of Durability (a) the new assigned weight and (b) the priorities rating of the alternatives

Finally, the last analysis was held for recycling and life cycle consideration factor. Similar conclusion can be made for the recycling and life cycle consideration factor, where PLA reinforced kenaf stayed as the best material choice for car door panel with a score of 60.6% as illustrated in Figure 4.35.



(a) (b)

Figure 4.35: Sensitivity analysis of Recycling and life cycle consideration (a) the new assigned weight and (b) the priorities rating of the alternatives

The sensitivity analysis performed showed the decision making is consistent. Although some significant changes were made on the criteria weights, but the choice of PLA reinforced kenaf as the best alternative was remained the same.

4.4 FINITE ELEMENT ANALYSIS (FEA)

4.4.1 Static Analysis

In this study, Acrylonitrile butadiene styrene (ABS) and PLA reinforced kenaf were used for car door panel to compare the static structural of the conventional material with new material. The results obtained for static analysis of conventional material and new material were compiled and tabulated in Table 4.4 and Table 4.5, respectively.

Table 4.4: Static analysis results for conventional material, Acrylonitrile butadiene styrene

Speed (km/hr)	Equivalent Von-Mises Stress (MPa)		Total Deformation (mm)		Maximum Principal Elastic Strain	
Material (ABS)	**Stress (min)**	**Stress (max)**	**Deformation (min)**	**Deformation (max)**	**Strain (min)**	**Strain (max)**
36	0.36415	372.92	0	80.633	-0.0042884	0.15835
72	0.17895	211.26	0	42.501	-0.0022715	0.090134

Table 4.5: Static analysis results for new material, PLA reinforced kenaf

Speed (km/hr)	Equivalent Von-Mises Stress (MPa)		Total Deformation (mm)		Maximum Principal Elastic Strain	
Material (PLA + Kenaf)	**Stress (min)**	**Stress (max)**	**Deformation (min)**	**Deformation (max)**	**Stain (min)**	**Strain (max)**
36	0.082809	107.06	0	6.0061	-0.0004532	0.012835
72	0.16562	214.13	0	12.012	-0.00090639	0.025669

The pictorial representation of equivalent von-mises stress was obtained when applying Acrylonitrile butadiene styrene (ABS) as the material during static analysis was given in Figure 4.36. When there was an acceleration of impact of 36 km/hour, the maximum stress obtained by finite element analysis was 372.92 MPa. Based on the figure below, it has been noticed that the stress concentration was located at irregular surface of the car door panel. Hence, it can be predicted that failure is more likely to occur at the irregular surface of the car door panel.

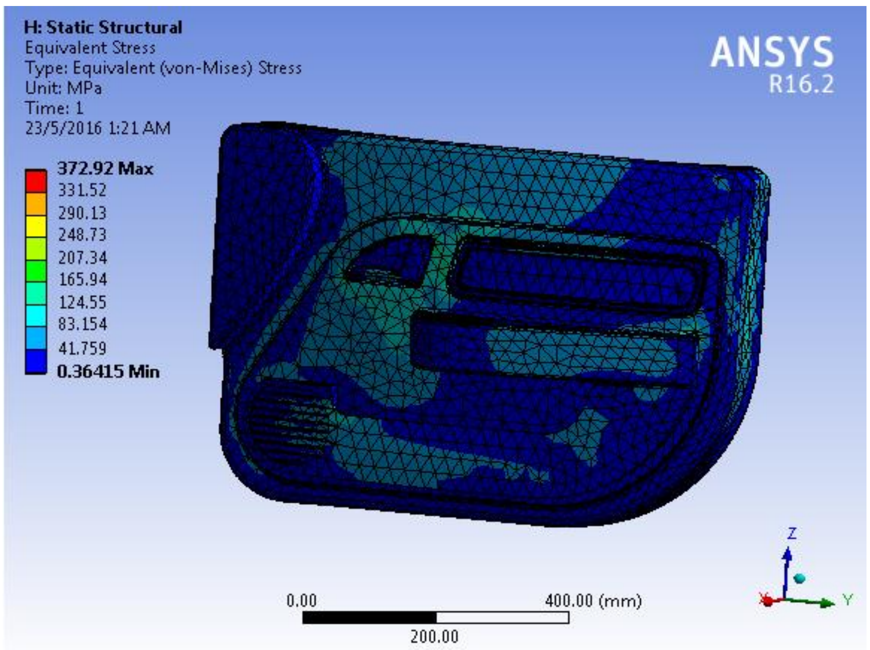


Figure 4.36: Equivalent von-mises stress distribution for ABS at 36km/hr

Figure 4.37 shows the displacement in magnitude before displaced. The maximum deformation value was recorded at 80.633 mm. Based on the analysis, the color (from red to blue) indicated the pointed value according to the maximum or minimum displacement that acted on the car door panel. As shown in the figure below, the displacement reduces at the uneven surface of the car door panel. The flat surface of the car door panel does not show any movement as it has been fixed by the boundary condition.

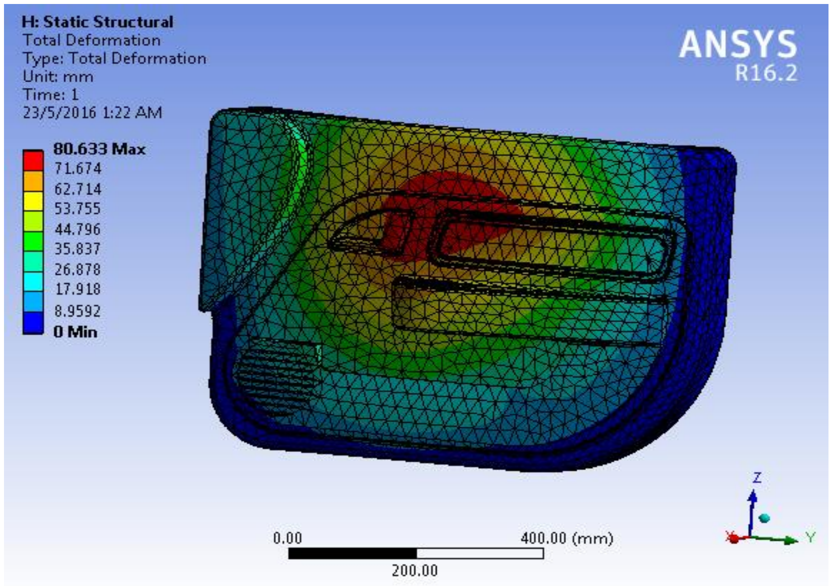


Figure 4.37: Total deformation obtained for ABS at 36km/hr

Figure 4.38 shows the analysis of maximum principal elastic strain in finite element analysis using ANSYS software. Based on the figure, it can be observed that the maximum strain was obtained 0.15385.

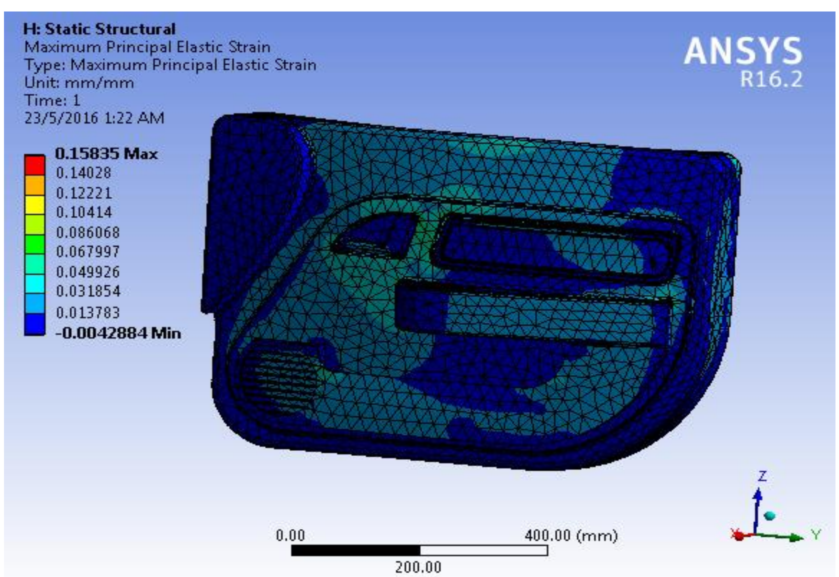


Figure 4.38: Maximum principal elastic strain obtained for ABS at 36km/hr

Figure 4.39 shows von-mises stress analysis result from the simulation when applying Acrylonitrile butadiene styrene (ABS) as the material during static analysis. When there was an acceleration of impact of 72 km/hour, the maximum stress obtained by finite element analysis was 211.26 MPa. From this figure, it can be observed that the stress concentration was located at the irregular surface of the car door panel. Besides, the stress concentration distributed averagely among the irregular surface. Thus, it can be concluded that failure is most likely to occur at the lower side of car door panel as it has higher stress concentration.

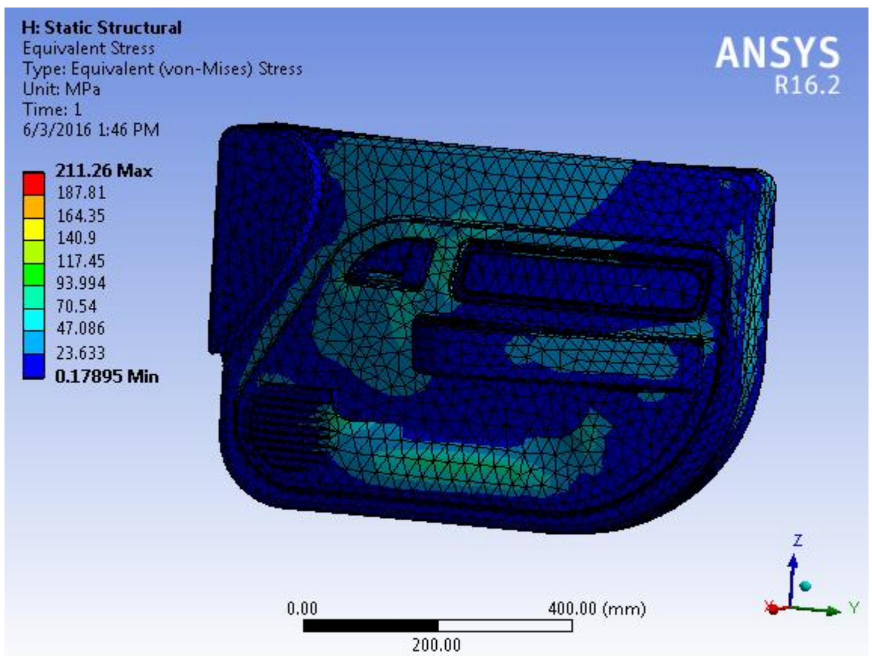


Figure 4.39: Equivalent von-mises stress distribution for ABS at 72km/hr

Figure 4.40 shows the results of total deformation when the car door panel was receiving an impact at 72km/hour. The maximum deformation value recorded was 42.501 mm and the maximum principal strain obtained in this case was 0.090134. From this figure, it showed the displacement magnitude of the front surface of the car door panel after a force of 285 kN was applied on the front surface in x-direction. From that, it can be observed that the deformation was likely to occur from the side to the center of the car door panel. The red color indicated the maximum displacement and blue color indicated the minimum displacement during deformation.

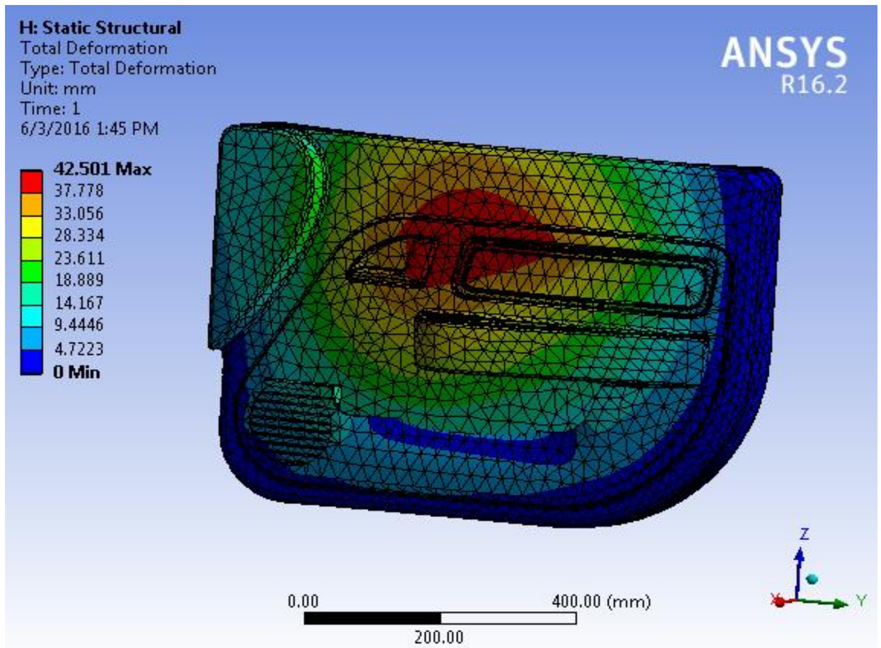


Figure 4.40: Total deformation obtained for ABS at 72km/hr

Figure 4.41 shows the simulation results of maximum principal elastic strain when there was an acceleration of impact of 72 km/hour. In this situation, the maximum strain was obtained at 0.090134.

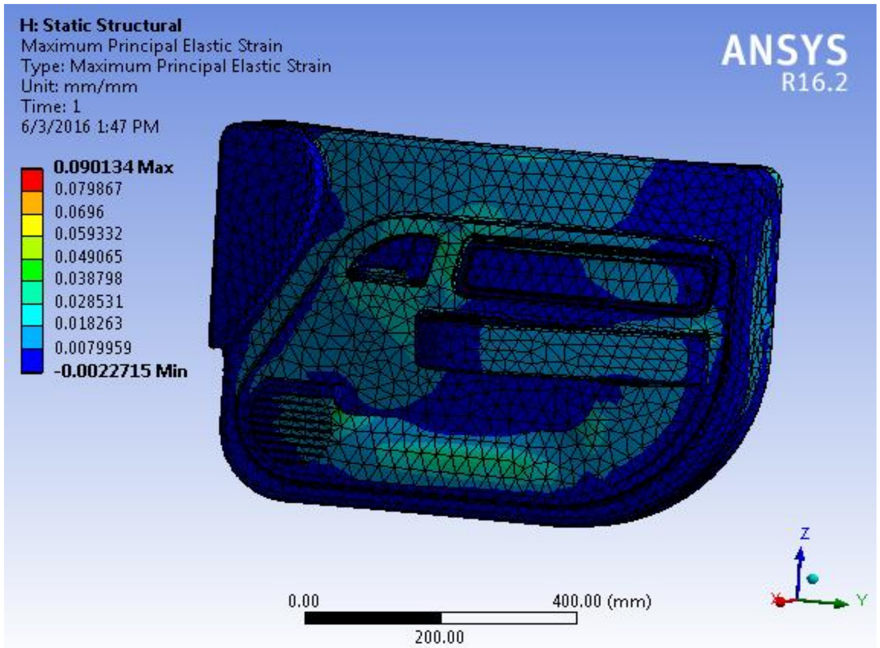


Figure 4.41: Maximum principal elastic strain obtained for ABS at 72km/hr

The pictorial representation of the equivalent von-mises stress for PLA reinforced kenaf when receiving an impact at a speed of 36km/hour was shown in Figure 4.42. The maximum von-mises stress was obtained in 107.06 MPa. Based on this figure, it can be observed that the stress concentration is at the middle and lower part of the car door panel. Failure might occur if a larger force is applied. However, as compared with conventional material, this new composite material showed higher maximum von-mises stress. Hence, it can said that PLA reinforced kenaf was stronger than ABS.

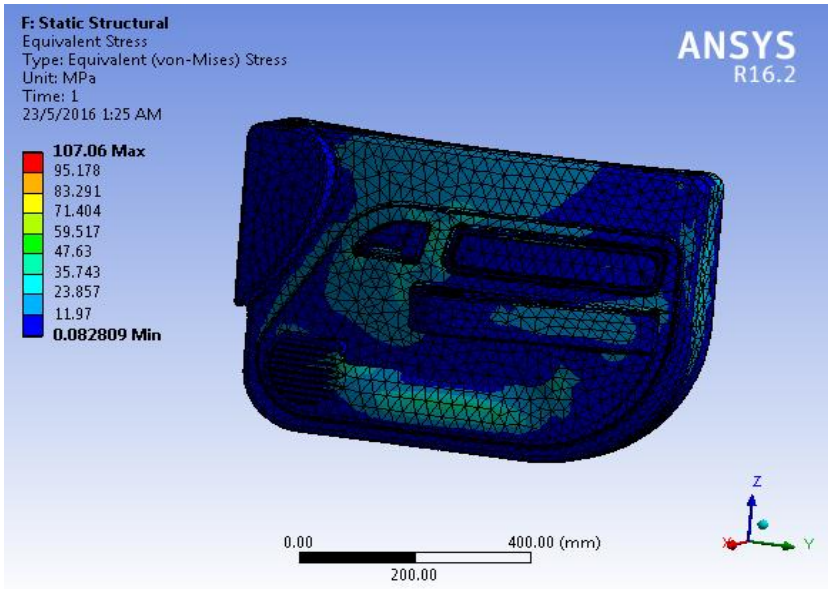


Figure 4.42: Equivalent von-mises stress distribution for PLA/Kenaf at 36km/hr

Figure 4.43 shows the results of total deformation of new material when there was an acceleration of impact of 36 km/hour. In this case, the value obtained for maximum displacement was 6.0061 mm which was the minimum among the comparison.

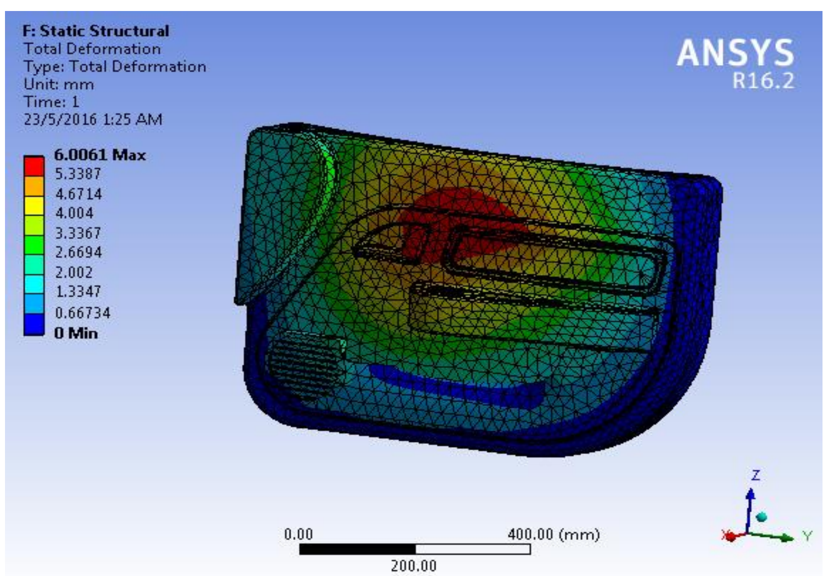


Figure 4.43: Total deformation obtained for PLA/Kenaf at 36 km/hr

In Figure 4.44, it shows the maximum principal elastic strain for PLA reinforced kenaf at 36 km/hour. The results obtained for this new material was 0.012835. There is a decrement in strain when change of material from ABS to PLA reinforced kenaf.

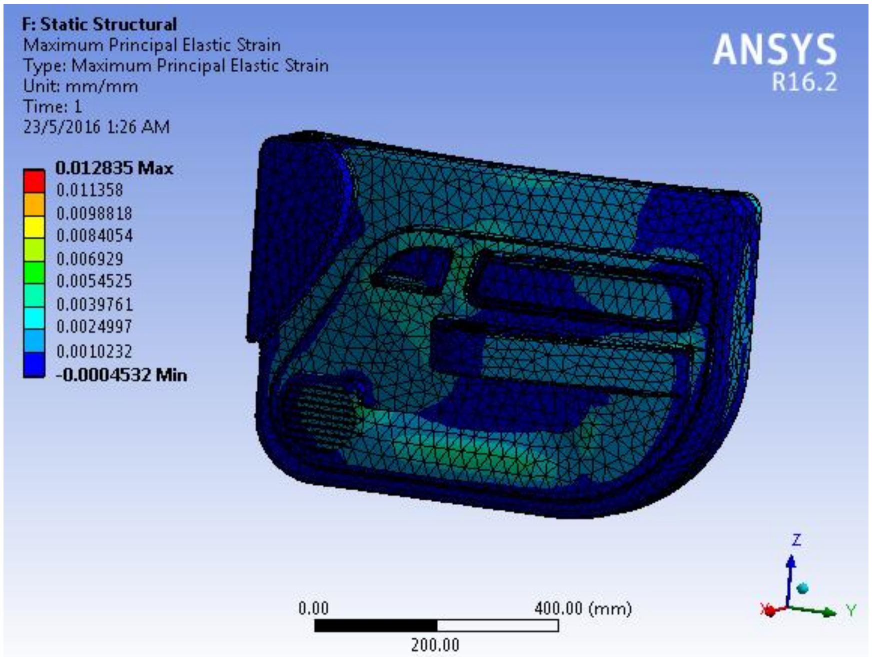


Figure 4.44: Maximum principal elastic strain obtained for PLA/Kenaf at 36 km/hr

The pictorial representation of the equivalent von-mises stress for PLA reinforced kenaf was given in Figure 4.45. When the car door panel is receiving an impact at a speed of 72 km/hour, the maximum von-mises stress was obtained in 214.13 MPa. This new composite material gave the maximum stress when comparing with the conventional material, since it was the strongest among the comparison. The results show there is an improvement in the strength of the car door panel as the maximum stress increases from change of material from ABS to PLA reinforced kenaf.

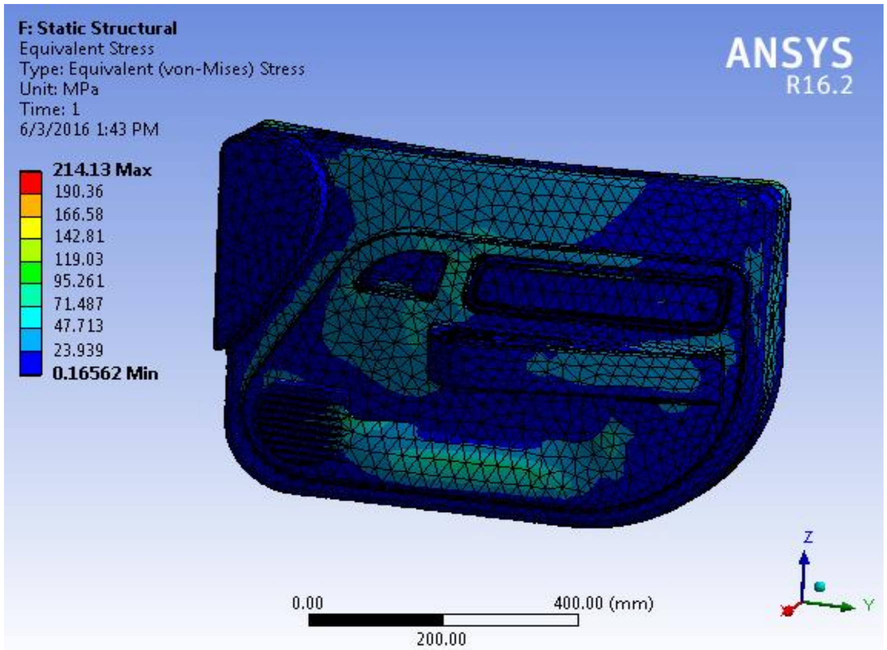


Figure 4.45: Equivalent von-mises stress distribution for PLA/Kenaf at 72 km/hr

While considering total deformation, the value obtained was 12.012 mm which was the minimum among the comparison. The maximum deformation of new material was reduced by 28.3% than the conventional material, ABS. The decrement of displacement value was because PLA reinforced kenaf composite has higher stiffness and higher tensile strength.

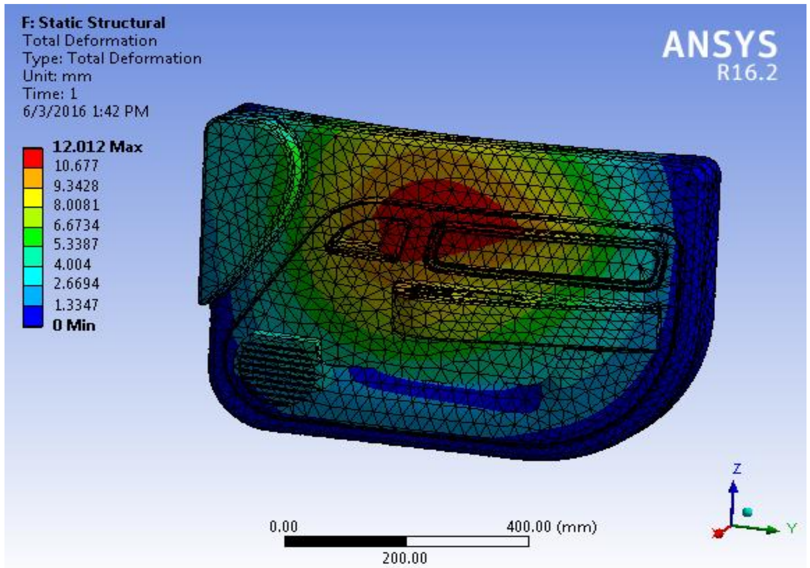


Figure 4.46: Total deformation obtained for PLA/Kenaf at 72 km/hr

The maximum principal strain obtained for this material was 0.025669. It shows the minimum strain value among the comparison with conventional material when the car door panel was being hit at a speed of 72 km/hour.

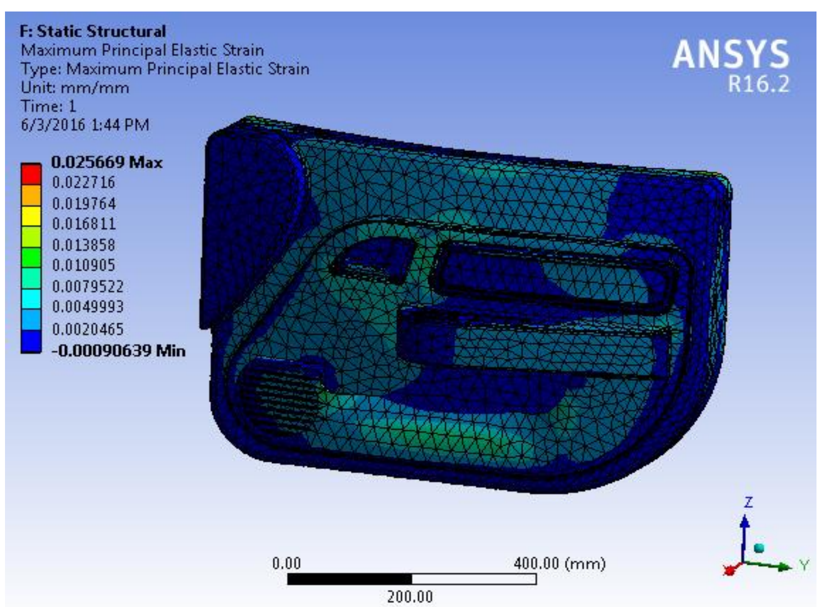


Figure 4.47: Maximum principal elastic strain obtained for PLA/Kenaf at 72 km/hr

From various analysis, it is to be concluded that PLA reinforced kenaf composite is the most optimum material which can use as the material for car door panel since it has met most of the requirements like high strength to weight ratio, crashworthiness and high stiffness to weight ratio. PLA reinforced kenaf composite possess the highest von mises stress value and the lowest deformation, which suits the best among the comparison.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

The research described in this thesis has been concerned with the material selection using bio polymer reinforced with natural fiber for car door panel. A new bio composite material for car door panel was proposed to improve the product performance and sustainability factor. An investigation of Quality Function Deployment (QFD) and Analytical Hierarchy Process (AHP) methods were carried out to select the most appropriate bio composite material for car door panel by considering the performance, lightweight, cost, durability and recycling and life cycle consideration. Meanwhile, based on the finite element analysis (FEA) using ANSYS software, it is concluded that the selected material, poly lactic acid (PLA) reinforced kenaf fiber composite meets most of the performance requirements like high strength and crashworthiness. From various analysis, the proposed methods were proved to be very effective in solving multi-criteria decision making where they are able to successfully come out with an optimized solution for high performance and sustainability material selection. The selected biodegradable composite material improves the safety of passenger as well as enhances the end-of-life vehicle recycling factor. Thus, the selected bio polymer reinforced with natural fiber composite material can be recommended to the automotive industry.

5.2 RECOMMENDATIONS FOR THE FUTURE RESEARCH

Although the results presented in this study have demonstrated the effectiveness of the proposed approach, the optimization of car door panel for material selection can be further developed to include risk and manufacturability in the future research. The risk and manufacturability criteria is a multi-objective and quantitative problem. Therefore, the proposed multi-criteria decision making method is highly recommended to optimize the efficiency and obtained a satisfying result. Meanwhile, it was suggested that the Analytical Hierarchy Process (AHP) method could be strengthened by integrating with the problem solving method of TRIZ to optimize the effectiveness of material selection. Integrating Analytical Hierarchy Process (AHP) with TRIZ helps to minimize cost waste and increase the design efficiency during the product development process. Perhaps TRIZ was differ from normal problem solving process, it works towards the problem systematically and creatively.

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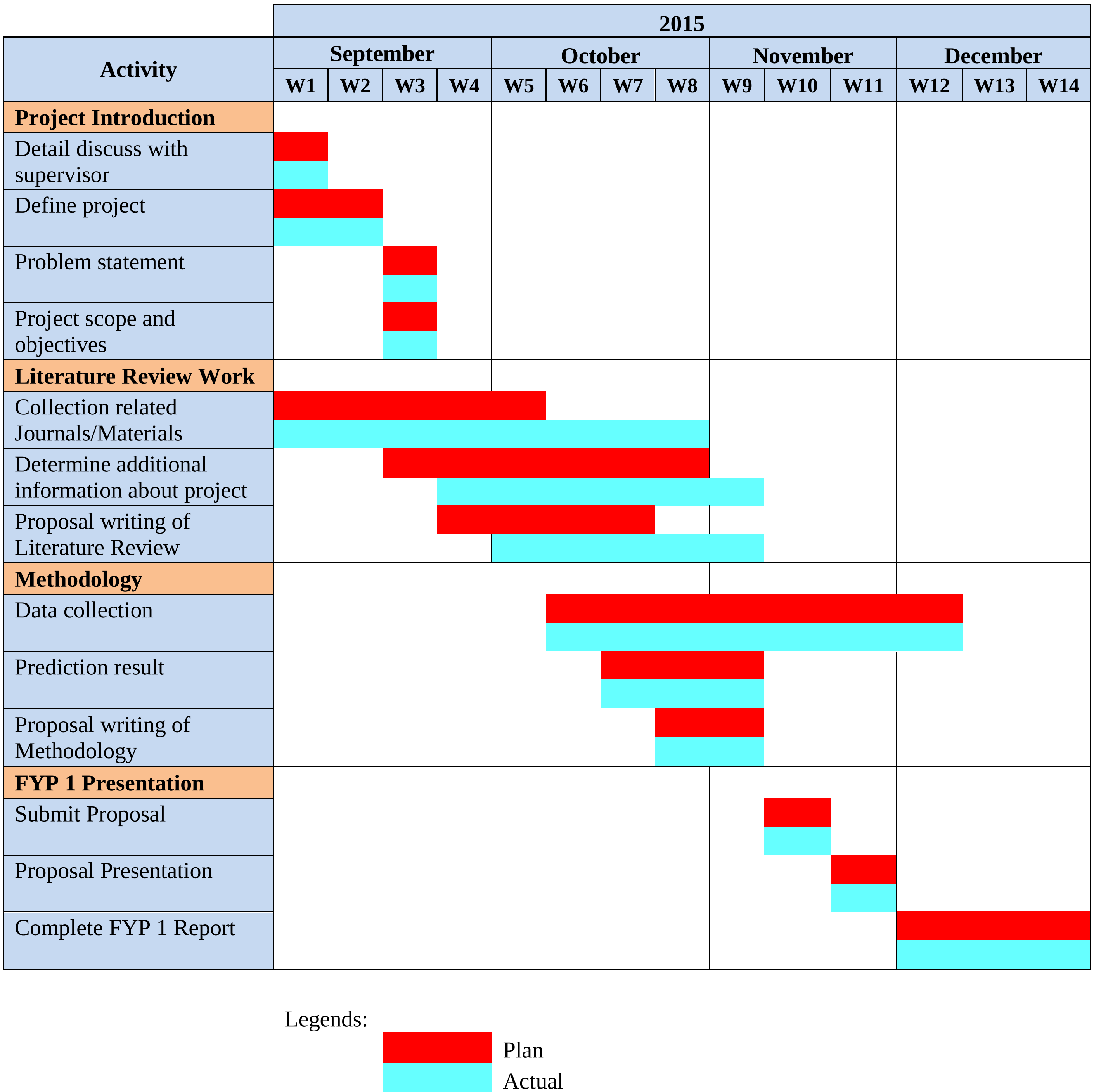
Appendices A1

Project Gantt chart for FYP 1



Appendices B1

Project Gantt chart for FYP 2