Material selection criteria for natural fibre composite in automotive component: A review

M Noryani¹,², S M Sapuan¹*, M T Mastura³, M Y M Zuhri¹ and E S Zainudin¹

¹Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
²Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
³Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

*Corresponding author: sapuan@upm.edu.my

Abstract. Emphasizing the green technology in manufacturing process with proper materials selection of natural fibre reinforced composite (NFRC) can save our future generation. There is multiple consideration of the criteria from the researcher for material selection process since the database of NFRC is not completely available. Product design specification (PDS) of automotive component is studied from past researcher with the summarized of the elements considered. Literature from year 2000 until year 2016 were collected which is focused on related automotive component design. In this study, it is found that the most commonly used elements of PDS of automotive component was consider from the previous researcher were cost, density, tensile strength, Young’s modulus and elongation at break. Generally, the mentioned elements are recommended to be considered by other researchers in automotive component design in material selection process.

1. Introduction

In recent years, the annual car production is increase in automotive industry by the year 2020. It will give a special advantage by emphasize renewable material and green operation in manufacturing process according to automotive perspective [1]. It’s become a good effort from the industry to overcome the projections world energy consumption 1990-2040 as reported by the International Energy Outlook [2]. In addition, a good green product can be delivered to the end user and give a good environment to the future generation. Based on World Nuclear Association, the electricity energy is the higher demand increase by more than two-thirds as overall energy in between 2011-2035 that may need a nuclear power suggested by major international report on energy. To beat this global issue in future, the design engineers should properly select the right materials in manufacturing process especially in automotive component to meet the standard product requirement by the industry.

In a recent year, an engineer keeps on seeking the best materials that can produce a better product with a satisfactory performance. The main factor is to meet the product design specification (PDS) for each of the automotive component before the assembly process of the product in a whole design and manufacturing process. Good materials, low cost, lightweight and performance are the factors that contribute to the last user which is customer. Finally, final product such as a car meet the
customer satisfaction and can reflect to the customer loyalty to the product [3-4]. Material selection is one of the critical processes in design and manufacturing of a product as shown in Figure 1. Ashby [5] describe the characteristic of one material can increase the precision of the product compare to a multiple and diversity of the materials characteristics. A good receipt of the materials will give a better performance on the physical, mechanical and environmental effect [6–10]. In fact, it can reduce cost and time [11–13].

Figure 1. A Framework of Design Process [5].

Determination the best material of natural fibre composite in manufacturing process is difficult compare to the synthetic fibre because the properties of this material was distinctive. The elements of physical, mechanical, chemical and environmental properties of NFRC are not consistent and diversity [14]. These composites are custom-made at least from two combinations of materials, it causes variety performance of the properties. These materials constraints become a conflict to the manufacturing process to fulfill the design requirement of automotive component in industry.

Most of the previous researcher study on material selection of automotive component application in car manufacturing such as clutch pedal, car front hood, buggy bonnet, brake disc, bumper beam, dashboard panel, break lever, car roof and anti-roll bar [15–23] were consider multiple criteria and sub criteria based on the application of the automotive component. In materials selection process, there are a lot of methods in multiple-criteria decision-making (MCDM) was used in varied application such as Analytical Hierarchy Process, Analytical Network Process, Multi-attribute Utility Theory, Preference Selection Index, Technique of Ranking Preferences by similarity of the Ideal Solutions, Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR), Elimination and Choice Expressing the Reality, Simple Additive Weighting, Data Envelopment Analysis, Preference Ranking Organization Method for Enrichment Evaluations, Quality Function Deployment, Quality Function Deployment for the Environment and questionnaire [24–27]. All these method is implemented by different approach such as computer aid engineering, knowledge-based expert, fuzzy and integrated method of MCDM [28–33]. Researcher should determine the criteria to desired properties of interest.
application before performing the analysis. In general, as observed from prior studies, the most researchers focus on four main properties which are physical, mechanical, chemical and environmental on their study.

This review paper attempts to provide a knowledge and idea to the new researcher about the major criteria used for material selection. The criteria, types of materials, case study on different automotive component from previous study was summarized. The major concern on types of criteria with command materials of fibre and matrix also listed in this study that will be a quit access to other researcher.

2. Design Material Selection and Requirement

By considering multiple characteristics of the composites can produce multiple performance of the materials and a proper procedure should be addressing to find the best output in automotive industry. Decision making on materials is extremely intuitive when considering single criterion problem. It can create a bias problem to other alternative materials. However, in the real world, the engineer should identify an appropriate criterion, goal, aspects, attributes and possible alternatives in MCDM. Most of MCDM used similar systematic evaluation steps which involving (1) determination the relevance criteria and feasible alternatives, (2) numerical measurement of the criteria and evaluation of the alternatives and (3) determining a ranking score of each alternatives [34].

Identification on factors and criteria at the beginning of selection process can perform a better judgment on the potential capabilities of the natural fibre composites [35]. A lot of features and properties should be considered in difference application. Decision maker need to identify the criteria or factors based on the application and PDS is used as a guide to the decision maker. In this study, the literature from year 2000 until 2016 was summarized and the criteria that influence the selection process is discussed as shown in Table 1. The most main criteria consider by the decision maker were physical, mechanical and environmental aspect [23], [29], [36-37]. Some researchers used these properties to select the concept design for a particular application such as selection of bumper system, brake disk, break lever and wheelchair [36], [38–40]. Consideration the criteria for selection process is one of the instrument on concurrent engineering [33]. From this review, more than 50 types of criteria were considered for material selection focusing in automotive component from 22 articles. We found the most commonly used criteria of PDS are cost, density, tensile strength, Young’s modulus and elongation at break. The description of top 10 criteria was explained in Table 2.

Besides physical, mechanical and environmental properties have been identified as major contributing factors for material selection by referring on Table 1, other factors such as chemical, maintenance, thermal and acoustic insulating properties are considered by minority of the researchers.

2.1 Product Design Specification (PDS)

Each of automotive component have a specific product design requirement. This PDS describe how a design is made, what it is intended to do and how far it complies with the requirement. The requirement is formal documented to be satisfied by the material, design, product and service generally. To avoid any automotive component failure during the product design testing, the engineer should optimize follow the PDS. For example, Davoodi et al. [54] consider design parameters such as thickness, bumper beam curvature and strengthening ribs to fulfil the desired PDS to produce vigorous bumper beam. Other than market investigation, conceptual design, detail design and manufacture, PDS is one of the main factors that should be consider in design stages as mentioned by Sapuan [15].
Table 1. Selection requirement for automotive component design.

| Description                                      | Design requirement          | Application          | Materials              | Author |
|--------------------------------------------------|----------------------------|----------------------|------------------------|--------|
| Material selection of natural fibre              | Density                     |                      | Sugar palm             | [23]   |
|                                                  | Elongation at break         |                      | Kenaf                  |        |
|                                                  | Micro-fibril angle          |                      | Oil palm               |        |
|                                                  | Fibres’ length              |                      | Sisal                  |        |
|                                                  | Moisture content            |                      | Jute                   |        |
|                                                  | Cellulose                   |                      | Hemp                   |        |
|                                                  | Hemicellulose               |                      | Flax                   |        |
|                                                  | Lignin                      |                      | Pineapple              |        |
|                                                  | Young’s modulus             | Anti-roll bar (ARB)  | Coir                   |        |
|                                                  | Bio-degradability           |                      |                        |        |
|                                                  | Raw cost                    |                      |                        |        |
|                                                  | Tensile strength            |                      |                        |        |
|                                                  | Availability                |                      |                        |        |
|                                                  | Production rate             |                      |                        |        |

| Material selection of matrix (thermoplastic)     | Density                     |                      | PP                     | [41]   |
|                                                  | Young’s modulus             |                      | PS                     |        |
|                                                  | Fracture toughness          |                      | HDPE                   |        |
|                                                  | Elongation at break         |                      | LDPE                   |        |
|                                                  | Tensile strength            | Anti-roll bar (ARB)  | TPU                    |        |
|                                                  | Impact strength             |                      |                        |        |
|                                                  | Chemical resistance         |                      |                        |        |
|                                                  | Water absorption            |                      |                        |        |
|                                                  | CO2 footprint               |                      |                        |        |
|                                                  | Raw cost                    |                      |                        |        |
|                                                  | Thermal conductivity       |                      |                        |        |
|                                                  | Recycle                    |                      |                        |        |
| Material selection of matrix (thermoplastic) | Material selection of natural fibre | Material selection |
|---------------------------------------------|-----------------------------------|-------------------|
| Tensile strength | Strength | Stiffness |
| Young modulus | Density | Cost |
| Elongation at break | Raw material cost | Water absorption |
| Impact strength | Heat deflection temperature | Availability |
| Coefficient of thermal expansion | Process melting temperature | |
| Raw material cost | Parking Brake | Parking Brake |
| Parking Brake | Lever | Lever |
| PP | Kenaf | Kenaf |
| LDPE | Oil palm | Jute |
| HDPE | Flax | Ramie |
| Nylon 6 | Hemp | Cor |
| Parking Brake | Sisal | Cotton |
| Lever | Bagasse | Coir |
| Parking Brake | Pineapple | Flax |
| Lever | Banana | Hemp |
| Parking Break | Car front hood | Parking Break |
| Lever | Kenaf | Jute |
| Parking Break | Sisal | Jute |
| Lever | Flax | Flax |
| Parking Break | Hemp | hemp |
| Lever | | |
Material selection
for buggy bonnet

| Property                  | Material       | Unit  |
|---------------------------|----------------|-------|
| Density                   | Flax           | g/cm³ |
| Young’s modulus           | Hemp           |       |
| Specific Young’s modulus  | Jute           |       |
| Tensile strength          | Abaca          |       |
| Specific tensile strength | Sisal          |       |
| Ultimate elongation at    | Coir           |       |
| break                     | E-glass        |       |

Material Selection

| Property                          | Unit  | Application          |
|-----------------------------------|-------|----------------------|
| Density                           | g/cm³ | Automotive, Biocomposites |
| Thermal conductivity              |       |                       |
| Coefficient of thermal expansion  |       |                       |
| Glass transition temperature      |       |                       |
| Acoustic insulation properties    |       |                       |
| Elastic modulus                   |       |                       |
| Fracture toughness                |       |                       |
| Elongation to break               |       |                       |
| Yield strength                     |       |                       |
| Impact strength                    |       |                       |
| Curing temperature                |       |                       |
| Curing pressure                   |       |                       |
| Curing time                        |       |                       |
| Resistance of chemicals           |       |                       |
| Level of hydrophobic nature       |       |                       |
| Weather resistance                |       |                       |
| Service temperature               |       |                       |
| Sunlight and UV resistance        |       |                       |
| Wettability                        |       |                       |
| Cost                              |       |                       |

[17] [42]
| Material selection | Young modulus | Dashboard panel | NFRPC | [20] |
|--------------------|---------------|-----------------|-------|------|
| Dent resistance (yield strength, panel thickness, panel stiffness) | Safety | Type of panel: Roof | Steel-BH | [22] |
| Ease of manufacturing | Size | Bumper beam for passenger | Steel-DP | [43] [44] |
| Noise, vibration, harshness (NVH) | Performance | Glass+Thermoplastic | Steel-HSLA |
| Density | Installation | Kenaf/Glass+Epoxy | Steel-martensite |
| Material cost, manufacturing cost | Materials | | Aluminium-5xxx |
| Temp. performance | Weight | | Aluminium-6xxx |
| Crashworthiness | Environment | | Magnesium |
| Durability | Process, Cost | | Titanium |
| Bending stiffness | Disposal | | GFRP |
| Torsional stiffness | | | HDPE |
| Material Selection          | Density | Permissible slide speed | Permissible pressure | Elastic modulus | Tensile strength | Thermal expansion coefficient | Thermal conductivity | Hardness | Wear resistance | Corrosion resistance | Heat-treatability | Manufacturability | Recycle cost | Material cost | Processing cost | Disposal | Reusability | Energy consumption | Polluting |
|-----------------------------|---------|-------------------------|----------------------|-----------------|-----------------|-------------------------|---------------------|----------|----------------|---------------------|-------------------|-------------------|--------------|--------------|------------------|----------|------------|-------------------|----------|
|                             |         |                         |                      |                 |                 |                         |                     |          |                |                     |                  |                   |              |              |                  |         |            |                   |         |
|                             |         |                         |                      |                 |                 |                         |                     |          |                |                     |                  |                   |              |              |                  |         |            |                   |         |

| Concept design selection   | Environment | Size | Weight | Materials | Standard | Patents | Safety | Cost | Performance | Maintenance | Manufacturing | Shape |
|----------------------------|--------------|------|--------|-----------|----------|--------|--------|-----|-------------|-------------|----------------|-------|
|                            |              |      |        |           |          |        |        |     |             |             |                |       |
|                            |              |      |        |           |          |        |        |     |             |             |                |       |
|                            |              |      |        |           |          |        |        |     |             |             |                |       |

*Automotive Engineering* [45]

| Automotive bumper beam | Glass+Epoxy | Carbon+Epoxy | Carbon+10%PP | Glass+40%PP | Glass+30%Polyester | Glass+60%Vinylester |
|-------------------------|-------------|--------------|--------------|-------------|-------------------|-------------------|
|                         |             |              |              |             |                   |                   | [46] |
|                         |             |              |              |             |                   |                   | [37] |

*Glass+40%PP* [37]
| Material selection | Performance (elastic modulus, density) | Interior motorcar panel | Polypropylene + hemp 40% | Polypropylene + flax 40% | Wood | Cork | [47] |
|--------------------|---------------------------------------|-------------------------|----------------------------|----------------------------|------|------|------|
| Material selection | Energy absorption | Automotive bumper beam | Glass fibre epoxy | Glass fibre-reinforced polypropylene (10%) | | | [19] |
| for polymeric composite | Impact toughness | | Carbon fibre epoxy | Glass fibre-reinforced polypropylene (40%) | | | |
| | Performance | | Carbon fibre-reinforced polypropylene (10%) | Glass fibre-reinforced polyester (30%) | | | |
| | Flexural strength | | Glass fibre-vinylester SMC | Glass fibre-reinforced polyester (30%) | | | |
| | Flexural modulus | | | | | | |
| | Cost | | | | | | |
| | Density | | | | | | |
| | Service conditions | | | | | | |
| | Corrosion resistance | | | | | | |
| | Water absorption | | | | | | |
| | Manufacturing process | | | | | | |
| | Shape | | | | | | |
| | Environment consideration | | | | | | |
| | Recycling | | | | | | |
| | Disposal | | | | | | |
| | Availability | | | | | | |
| Design | Strength | Eco-aware lightweight automotive friction materials | Kenaf | | | | [12] |
| Processing | Stiffness | | Jute | | | | |
| Materials | Density | | Ramie | | | | |
| | Maximum service temperature | | Asbestos | | | | |
| | Durability with water | | | | | | |
| | Toxicity | | | | | | |
| | Price | | | | | | |
| | Energy and co2 footprint | | | | | | |
| | Safe for disposal | | | | | | |
| Material selection of natural fibre composite | Density | Young’s modulus | Biodegradability | Toxic level | Material cost | Manufacturing cost | Automotive component |
|---------------------------------------------|---------|-----------------|------------------|-------------|---------------|-------------------|---------------------|
| Material selection                          |         | Tensile strength|                  |             |               |                   |                      |
| Material selection                          |         |                  |                  |             |               |                   |                      |
| Material selection                          |         |                  |                  |             |               |                   |                      |
| Material selection                          |         |                  |                  |             |               |                   |                      |
| Material selection                          |         |                  |                  |             |               |                   |                      |

**Material selection**

- Compressive strength
- Friction coefficient
- Wear resistance
- Thermal conductivity
- Specific gravity
- Cost

**Automotive brake disc/rotor system**

- Cast iron (GCI)
- Aluminium alloy (based metal matrix composite)
- Titanium alloy
- Ceramics
- Composites

**Material selection**

- Density
- Porosity
- Microstructural analysis
- Hardness
- Compressive Strength
- Compressive Strain
- Compressive Load

**Automotive Break Pad**

- Coconut fibre reinforced composite

**Material selection**

- High strength to weight ratio
- Easy manufacturing
- Cost
- Longer life
- High oxidation and Corrosion resistances
- Higher creep and fatigue resistances

**Spar of Human Powered Aircraft**

- Super Alloys
- Hastelloy S, X
- Haynes HR-120, 160
- Haynes 230, 282, 625
- Inconel 600, 601
- CMSX-4

References:

- [48]
- [18]
- [50]
- [51]
### Material selection for thermal conductor

| Property                  | Example Materials                                      |
|---------------------------|--------------------------------------------------------|
| Density                   | Copper-2-beryllium, Copper-cobalt-beryllium           |
| Compressive stress        | Electrolytic tough-pitch, copper, soft                |
| Ultimate tensile stress   | Electrolytic tough-pitch, copper, hard                |
| Spring back index         | Wrought aluminium alloy                                |
| Bend force index          | Wrought austenitic stainless steel                     |
| Static load index         | Commercial bronze, soft                                |
| Hardness                  | Carbon steel                                           |
| Yield stress              |                                                        |
| Elastic modulus           |                                                        |
| Thermal diffusivity       |                                                        |
| Thermal conductivity      |                                                        |
| Cost                      |                                                        |

### Material selection

| Property                  | Example Materials                                      |
|---------------------------|--------------------------------------------------------|
| Failure strength          | 300M                                                   |
| Fracture toughness        | 2024-T3                                                |
| Density                   | 7050-T73651                                            |
| Price                     | Ti-6Al-4V                                              |
| Fragmentability           | E glass-epoxy                                           |
|                           | S glass-epoxy                                           |
|                           | Carbon-epoxy                                            |
|                           | Kevlar29-epoxy                                          |
|                           | Kevlar49-epoxy                                          |
|                           | Boron-epoxy                                             |

### Material selection

| Property                  | Example Materials                                      |
|---------------------------|--------------------------------------------------------|
| Strength                  | Polymetric based composite                            |
| Modulus                   |                                                        |
| Manufacture               |                                                        |
| Cost                      |                                                        |
| Clutch pedal              |                                                        |

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[52] [53]

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Table 2. The criteria of automotive component [23].

| Criteria of PDS        | Description                                                                 |
|------------------------|----------------------------------------------------------------------------|
| Density                | The degree of consistency measures by the quantity of mass per unit volume  |
| Tensile strength       | The resistance of a material to breaking under tension                      |
| Young's modulus        | The measurement of elasticity, ratio of the stress to strain                |
| Thermal conductivity   | The rate at which heat passes through on material, the amount of heat that  |
|                        | flows per unit time through a unit area with a temperature gradient of one  |
|                        | degree per unit distance                                                    |
| Cost                   | The price of raw materials and manufacturing                               |
| Elongation at break    | The capability of a material to resist changes of shape without crack       |
|                        | formation                                                                   |
| Fracture toughness     | The ability of a material containing a crack to resist                      |
| Water absorption       | The fluid uptake on the material                                            |
| Stiffness              | The ability of an object to resist deformation in response to an applied    |
|                        | force                                                                       |
| Easy of manufacturing  | The process of converting raw materials, component or part into finished    |
|                        | goods                                                                       |

2.2 Materials

In this review, most of the reference used natural fibre reinforced composite as the material for selection process. The combination of natural fibre and the matrix will enhance the properties of the composite for example a hybrid materials from sugar palm fibre and fibre glass in fabrication of boat can increase the tensile and impact properties of the composites [55]. In different study by Ishak et al. [56] also show the composites reinforced with kenaf bast fibres produce better score on tensile, flexural and impact test compare with kenaf core fibre composites with different level of fibre loading. The advantages of the composite are low density and high specific strength and stiffness [57–59]. Moreover, the fibre from the composite is renewable resources which need less energy production and can reduce CO₂ [60]. The most preferable concern used this material was the cost which it’s cheaper compare to synthetic fibre [11]. Joshi et al. [61] compare the natural fibre and glass fibre with comparative life cycle assessment and found that the natural fibre composite achieve higher on key driver of their relative environmental performance. However, the composite has wider variability of properties because of the diversity combination from the fibre and matrix itself. On the other hand, high moisture absorption of the composite will result swelling [62], [63]. The low durability problem of the composite can be improved with the chemical treatment such as two different alkali pre-treatment treated palm fibre reinforces mortars can increase the durability and other mechanical properties studied by Ozerkan et al. [64]. The salt-fog environment condition also can be considered as a practical approach for enhancing the durability of natural flax fibre with external basalt layers [65]. Different consideration on geometry parameter by Davoodi et al. [54] such as cross section, thickness, added ribs and fixing method optimizations can improve the impact properties in epoxy composite bumper beam. From this review on material selection, most of the researchers used NFRC on their studies. The top five natural fibre was jute, hemp, flax, kenaf and coir. It is because these natural fibres are easy to handle and process during the experimental work. Furthermore, the properties of these natural fibres are available. In this study, we found that polypropylene (PP), high density polyethylene (HDPE) and low density polyethylene (LDPE) are the command matrix used as the reinforced material to the fibre due to high recyclable of these thermoplastic nature compared to thermosetting such as epoxies and silicones. The application by using natural fibre for automotive component is a good transformation in automotive industry. Besides, based on Table 1 there is still metal based material used such as steel, aluminium and alloy for critical automotive component like turbine blade, thermal conductor and brake disc.
3. Discussion

Material selection process depends on the application and decision-making tools that may vary the result accordingly. As shown in Mansor et al.’s [21] study, kenaf fiber was selected as the most suitable natural fiber for lever break with regards to its design specifications. While, Mastura et al. [23] obtained sugar palm as the most suitable natural fibre in their study for the automotive anti roll bar using different method of decision making. Different study also considers different requirement such as environmental aspect, customer voice and design and manufacturing guideline. The selection process on natural fibre and matrix is done separately by the authors like Mansor et al. [40] and Mastura et al. [41]. This kind of implementation can be applied by others researcher or product design engineering that interested on single materials at the beginning of product design requirement on manufacturing process. In addition, the finding can contribute to a satisfactory performance on the final composite. Different practice done by Farag [47] and Ahmad Ali [48] which selection process is done on the composite which focus on certain type of matrix for example PP is selected as the matrix for the composite on automotive component application studied by Ahmad Ali et al. [48].

In other application on buggy bonnet, Furtado et al. [17] shown the jute fibre composite have higher damping behaviour compare to glass fibre. The jute fibre is a realistic choice in automotive application where the attenuation of vibration and noise is desirable. Kenaf was identified as an appropriate NFC to achieve the transportation weight reduction on application of car front hood by using VIKOR [16]. A study done by Mustafa et al. [12] also found kenaf have a potential as an alternative sources of friction materials not only consider the design requirement but impact on environment and human health is count into the study.

The concept of different application will have different criteria also practical in other industry such as in medication, the medical device consider availability, design flexibility, cost per unit, performance properties, regulatory compliance, bio-compatibility, aesthetics and usability, manufacturing efficiency, sterilization and cleaning and sustainability for choosing the right materials for the medical device design [66].

4. Conclusion

Numerous types of criteria were considered from the researcher in year 2000 until 2016 on different automotive component application for material selection. From over 50 types of criteria was summarized, we can conclude the most criteria used for material selection to satisfy the PDS in automotive industry were cost, density, tensile strength, Young’s modulus and elongation at break. Furthermore, the availability, ability and flexibility of these natural fibre such as jute, hemp, flax, kenaf and coir were the reason they become the favourite natural fibre used in automotive component. In addition, the command filler to the natural fibre was PP, HDPE and LDPE. From this study, the finding can be used to other researcher to start their study on automotive component design in material selection process generally.

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