MATERIAL SELECTION OF THERMOPLASTIC MATRIX FOR HYBRID NATURAL FIBER/GLASS FIBER POLYMER COMPOSITES USING ANALYTIC HIERARCHY PROCESS METHOD

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ABSTRACT

In this paper, Analytic Hierarchy Process (AHP) method was applied in the selection of the most suitable thermoplastic polymer matrix for hybrid natural fiber/ glass fiber polymer composites application. The hybrid polymer composites will later be applied for the construction of automotive parking brake lever component. The material selection process was conducted based on product design specifications of the parking brake lever to meet the operational requirements as well as sustainability advantages. Based on literature review, six (6) typical thermoplastic matrices used in natural fiber polymer composites fabrication were identified as the alternatives to satisfy the objectives. A 4-level AHP structure was applied in this project which consists of four (4) main criteria and seven (7) sub-criteria. Final selection results revealed that low density polyethylene (LDPE) thermoplastic matrix is the most suitable candidate material for the intended application compared to other identified thermoplastic matrices based on the highest priority ranking score. Consistency analysis was also performed where the overall consistency ratio throughout the analysis obtained was within the acceptable value of less than 0.10. Furthermore, to further validate the obtained results, sensitivity analysis was also conducted by varying the weight of the main criteria. Results from the sensitivity analysis also showed that LDPE matrix emerged with the highest score in all simulated scenarios which correctly respond to the results suggested from the AHP method.

Keywords: material selection, polymer composites, thermoplastic matrix, Analytic Hierarchy Process method

1. Introduction

Recent trends in automotive design worldwide have seen more emphasize towards addressing sustainability issue a part from meeting operational requirements of the component design especially in the early product development stage (Bernasconi, Davoli, & Armanni, 2010; Fontaras & Samaras, 2010). Among the emerging solutions to meet both objectives is the application of hybrid natural based polymer

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composites in automotive component development (Aji, Zainudin, Abdan, Sapuan, & Khairul, 2012; Davoodi et al., 2011). Polymer composites generally encompass two major components which are the fiber which act as the reinforcement and the matrix which holds the fiber together and allow the composites to be produced in various shapes. However, the task of selecting the most appropriate matrix can be very challenging due to the variability of the resin available to be combined with the fibers and various attributes that need to be satisfied simultaneously by the candidate material to suit the intended application.

Thus, in this project, multi attribute decision making approach using Analytic Hierarchy Process (AHP) method was applied to select best thermoplastic matrix for hybrid natural fiber/glass fiber polymer composites for automotive parking brake design. Thermoplastic matrices are the most suitable solution to meet the automotive design sustainability requirements due to their eco-friendly properties such as reusable, recyclable and safe for disposal compared to their thermoset matrices counterpart (El-Shekeil, Sapuan, Abdan, & Zainudin, 2012). The selection criteria involved in the thermoplastic matrix material selection process considers design for operational requirements which are functional performances (strength, stiffness and resilience to water absorption), lightweight and low product cost. Those requirements are then translated to four main criteria (performance, weight, service condition and cost) and seven sub-criteria (tensile strength, Young's modulus, impact strength, density, resistance to water absorption, raw material cost and material processing melt temperature) for the AHP analysis. Expert Choice v.11.5 software is used to perform the material selection task using AHP method.

2. Material Requirements for Automotive Parking Brake Lever

Parking brake is an essential part of a vehicle braking system. The main purpose is to hold the vehicle in stationary condition safely during stop and when idling. For a rear operated parking brake system, in general, there are three types of parking brake lever used which are the stick type, pedal type and center lever type parking brake lever. Among them, the former is more commonly used for passenger vehicles and is hand operated by the driver. The parking brake lever is provided with a ratchet locking mechanism to maintain the lever at a position to which it was set, until released and is made from hot rolled mild steel or SPHC steel due to strength and cost requirements. The brake lever is dominantly operated in bending load case with respect to its operating mechanism. Figure 1 shows an example of a center lever parking brake used in a Malaysian made national car.

(a) (b)

Figure 1: Example of a center lever parking brake design in (a) assembly view, and (b) exploded view

There are various requirements involved in selecting the appropriate material for automotive product development. In general, the material specifications varies according to the type of loading condition exerted to the component during operation, the surrounding operating condition that interacts with the component, cost consideration, government legislations and directives with regards to the automotive sector and more recently the impact of the material to the environment and the human being. Among the design requirements examples are stiffness, strength, reduced weight and manufacturing cost for armrest frame design (Park & Dang, 2011), mechanical property (tensile strength and Young's modulus) and physical property (density) for dashboard design (Sapuan et al., 2011), elongation, tensile strength, thermal conductivity, weight, recyclability, maximum temperature limit, toxicity level and material cost for instrument panel (Girubha & Vinodh, 2012), impact strength, weight, cost criteria and ease of manufacture for bumper beam (Hosseinzadeh, Shokrieh, & Lessard, 2005) and stiffness, strength, size, weight, design standards (such as BS7178, FMVSS 105, ECE R13 and ADR31), water absorption, ergonomics and cost for pedal components (Sapuan, 2005).

In determining the material requirements for the parking brake lever, the component product design specifications (PDS) were developed based on the information gathered through literature review and review of documents from the car manufacturer as shown in Figure 2. Based on the PDS, related requirements are extracted and implemented for the thermoplastic matrix material selection in this study.

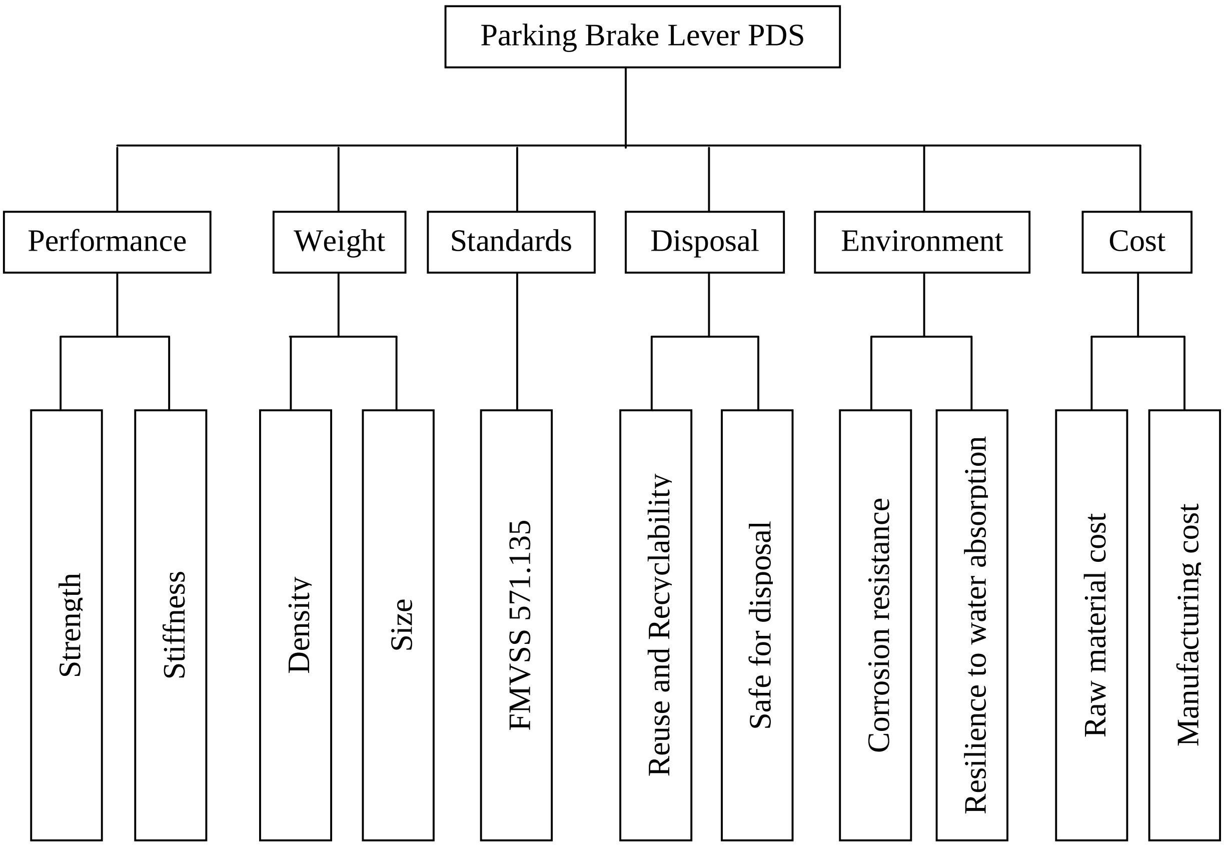

Figure 2: Product design specifications for automotive parking brake lever

3. Project Methodology

In general, the AHP method applied in this project involved 5 main stages which are developing the AHP hierarchy framework, performing pair-wise comparison between the identified set of criteria, sub-criteria and alternatives, synthesizing the pair-wise comparison data and ranking the best alternative that match the required goal based on overall priority vector values, and finally analyzing the consistency of the judgment made based on consistency ratio values (Kardi, 2006). The advantage to determine the consistency for all the decision made during the AHP analysis is regarded as one of the reason why AHP method is among the most applied solution tool nowadays especially in complex multi criteria decision making situations (Jahan, Ismail, Sapuan, & Mustapha, 2010). In the final part of this project, sensitivity analysis was also performed after the AHP analysis to further validate the obtained solution using Expert Choice software (Hambali, Sapuan, Ismail, & Nukman, 2010).

Furthermore, a 4-level AHP hierarchy framework was developed for the thermoplastic matrix material selection. At level-1, the main goal was set as to select the best thermoplastic matrix for hybrid natural fiber/glass fiber polymer composites. Level-2 and level-3 were dedicated to the material main criteria and sub-criteria that are considered with respect to the project goal. All the criteria chosen were based on the developed PDS for the component, with inclusion of the impact property as additional requirement for the matrix material selection. In total, the hierarchy involved four main criteria (performance, weight, service condition and cost) and seven sub-criteria (tensile strength, Young's modulus, impact strength, density, resistance to water absorption, raw material cost and material processing melt temperature) for the AHP analysis. Finally at level-4, all the identified alternatives which are the most common thermoplastic matrix associated with natural fiber polymer composites fabrication are listed which are polypropylene (PP), low density polyethylene (LDPE), high density polyethylene (HDPE), polystyrene (PS), as well as two variants of nylon or polyamide matrix which are Nylon 6 and Nylon 6,6. Figure 3 illustrates the overall AHP hierarchy framework used for the material selection process in this project.

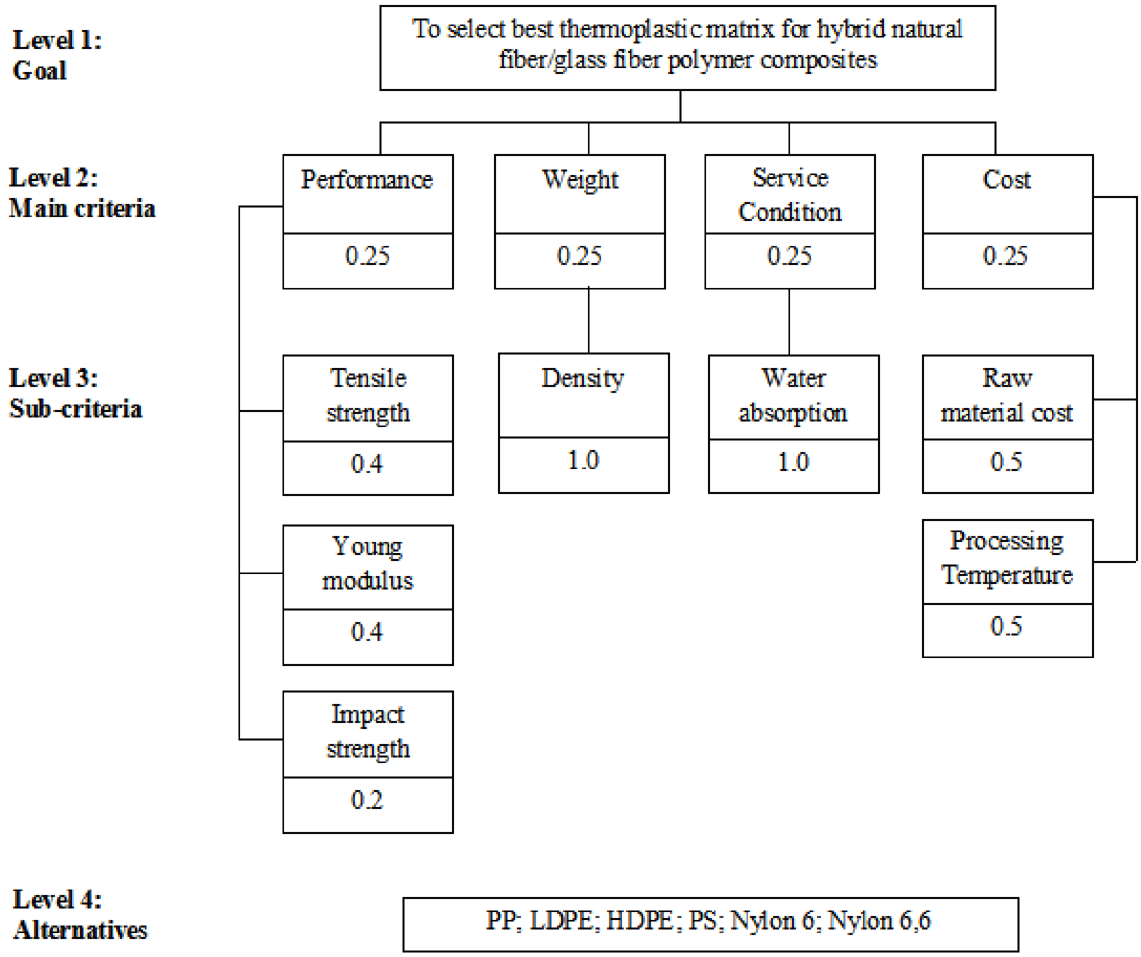

Figure 3: Thermoplastic matrix material selection using 4-level AHP hierarchy with priority vector values for main criteria and sub-criteria

Throughout the pair-wise comparison process, the judgment made involving the alternatives materials were based on the material information data obtained from the literature review. Meanwhile, for pair-wise comparison related to the criteria and sub-criteria with respect to goal, relative importance scale of 1 to 9 is used and the judgment decision were based on the authors' experience and knowledge through journals, patents and handbooks which is similar to the method used by Hambali, Sapuan, Ismail, and Nukman (2009). Table 1 and Table 2 show the properties of typical thermoplastic polymers for natural fiber polymer composites fabrication and the relative pair-wise scale used in the pair-wise decision making process.

Table 1: Properties of Typical Thermoplastic Polymers used in Natural Fiber Polymer Composites Fabrication (Holbery & Houston, 2006; Anon, 2012)

Resin	**Tensile strength (MPa)**	**Young Modulus (GPa)**	**Impact Strength (J/m)**	**Melting temperature (^{o}C)**	**Density (g/cm^3)**	**Water absorption – 24 hours (%)**	**Raw material cost (USD/lb)**
PP	26-41.4	0.95-1.77	21.4-267	160-176	0.899-0.920	0.01-0.02	0.95-0.98
LDPE	40-78	0.055-0.38	>854	105-116	0.910-0.925	<0.015	1.05-1.07
HDPE	14.5-38	0.4-1.5	26.7-1068	120-140	0.94-0.96	0.01-0.2	0.89-0.91
PS	25-69	4-5	1.1	110-135	1.04-1.06	0.03-0.10	1.18-1.22
Nylon 6	43-79	2.9	42.7-160	215	1.12-1.14	1.3-1.8	2.08-2.12
Nylon 6,6	12.4-94	2.5-3.9	16-654	250-269	1.13-1.15	1.0-1.6	1.98-2.09

Note: PP= Polypropylene, LDPE = Low Density Polyethylene, HDPE = High Density Polyethylene, PS = Polystyrene, Nylon = Polyamide

Table 2: Importance scale for pair-wise comparison analysis (Hambali, et al., 2010)

Relative intensity	**Definition**
1	equal importance
3	Slightly more importance
5	Essential or high importance
7	Very high importance
9	Extreme importance
2,4,6,8	Intermediate values between two adjacent judgements
Reciprocals	Reciprocals for inverse comparison

***Note:* i) If judgement value on the left side, actual judgement value is taken, ii) If judgement value on the right side, reciprocal value is taken.**

4. Results and Discussion

Final material selection results using AHP method as shown in Figure 4 revealed that low density polyethylene (LDPE) thermoplastic matrix scores the highest results (0.225), followed by polypropylene (0.192), polystyrene (0.165), high density polyethylene (0.158), nylon 6,6 (0.136) and nylon 6 (0.124). This shows that LDPE is the most suitable candidate material for the intended application compared to other identified thermoplastic matrices based on the highest priority ranking score. The consistency for all the selection decisions made through pair-wise comparison technique in this method was also kept to within the allowable recommended consistency ratio value of less than 0.10. The low consistency ratio is obtained through the availability of the material information used during the pair-wise comparison stage, which makes the judgment process less subjective and more accurate between the analyzed alternatives.

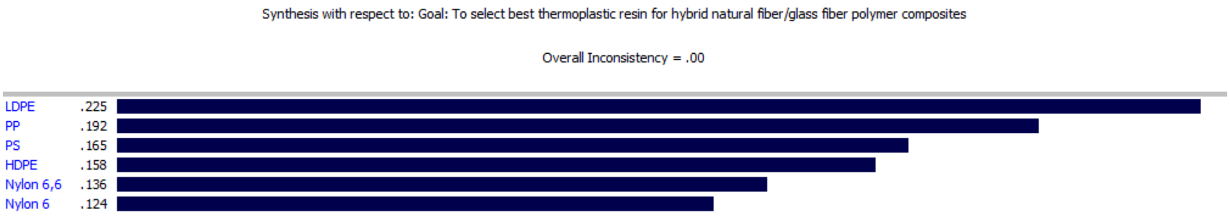

Figure 4: Overall synthesis results of the AHP analysis for thermoplastic matrix material selection

4.1 Sensitivity Analysis

To further validate the results obtained from the AHP analysis, sensitivity analysis using Expert Choice software was conducted by simulating several what-if scenarios through changing the weight of the main criteria with respect to the goal was also performed in this project (Sapuan et al., 2011). The sensitivity analysis results as shown in Table 3 demonstrated that LDPE matrix emerged with the highest score in all simulated scenarios which correctly respond to the results suggested from the AHP method performed previously.

Table 3: Rank of thermoplastic matrices priority corresponding to various scenarios simulated using sensitivity analysis for different main criteria with respect to goal

Rank	Performance Increased by 25%		Weight Increased by 25%		Service Condition Increased by 25%		Cost Increased by 25%	
	Thermoplastic matrix	Priority vector (%)	Thermoplastic matrix	Priority vector (%)	Thermoplastic matrix	Priority vector (%)	Thermoplastic matrix	Priority vector (%)
1	LDPE	20.0	LDPE	21.1	LDPE	31.7	LDPE	22.1
2	PS	17.6	PP	18.9	PP	25.3	PP	18.9
3	Nylon 6,6	17.0	HDPE	16.4	PS	13.5	HDPE	17.6
4	PP	16.4	PS	16.3	HDPE	11.8	PS	17.1
5	HDPE	15.0	Nylon 6,6	14.0	Nylon 6,6	9.2	Nylon 6,6	12.4
6	Nylon 6	14.0	Nylon 6	13.2	Nylon 6	8.4	Nylon 6	12.0

5. Conclusions

This project was successfully completed with several conclusions as follows:-

i) low density polyethylene (LDPE) thermoplastic matrix is the most suitable candidate material for hybrid natural fiber/glass fiber polymer composites
ii) overall consistency for the judgment made in the analysis is within the recommended consistency ratio value of less than 0.10
iii) sensitivity analysis results validated the AHP results of selecting LDPE as the best matrix material for the intended application

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