Selection of natural fiber for fiber metal laminate

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ABSTRACT – Due to the increasing awareness on environmental impact and subsequently the needs towards sustainability, weight reduction of the vehicles is one of the most promising solution towards achieving the reduction in CO^2 emissions which improves the fuel efficiency. Fibre metal laminate is a new range of lightweight hybrid materials with high fatigue resistance, toughness, strength and energy-absorbing capacity. Natural fibre-reinforced composites have been attracting the attention of scientists and manufacturers as they are biodegradable, environmentally friendly, lightweight, and inexpensive. Therefore, the interesting physical and mechanical properties exhibited by a combination of natural fibre and metal laminates deserve further investigation. This research presents the selection of the natural fibre for fibre metal laminates for use in automotive body panels. The material selection was carried out using CES Edupack software and the Pugh method for analysis. Based on the analysis kenaf fibre was determined to be the appropriate material that fulfilled the objective constraints of this study, namely, lightweight materials at a minimal cost with maximum performance.

1. INTRODUCTION

Demand for lightweight materials is gaining attention since weight reduction has been recognized as one of the key measures to reduce the fuel consumption. One of the lightweight material that currently being explored is fibre metal laminate (FML), a hybrid composite material consisting of interlacing layers of thin metals sheets bonded to fibre reinforced composite [1].

FML offer great potential for reducing the weight of vehicles. Studies on natural FML have been increasing since the inherent advantages of the natural fibre such as light weight, cost effective and environment friendly. Ng et al. [2] and Sivakumar et al [3] studied the fatigue life behaviour of bio-based and hybrid bio-based FML. Subramaniam et al. [4] studied the effects of stacking configuration on the response of tensile and quasi-static penetration to woven kenaf/glass hybrid composite metal laminate. Ishak et al. [5,6] studied the application of natural FML as car front hood.

However, limited numbers of work have been carried out on suitable material selection for the fabrication of the natural FML. Therefore, the objective of this study is to determining the best natural fibre for the fabrication of FMLs for car body panels using the CES approach, followed by Pugh method of analysis.

2. RESEARCH METHODOLOGY

2.1 CES Edupack

CES is developed by Ashby that provides a database of more than 3000 materials and process information that help in selecting materials and process to meet the desired complex design requirements. The optimal potential materials can be ranked using the desirable criteria or properties that meet the design's requirements. The summary of the top-ranking candidates will enable the material with the highest-ranking score to be selected as the best choice. Mustafa et al. [7] summarized four steps in CES as problem statement, objective function, objective constrains and best solution selection.

The objective of this study is to define appropriate natural fibre for the fabrication of FMLs' fibre reinforced composite as automotive body panels with a capable functional performance. The objective constraints involved is biodegradable. Table 2.1 shows the function and criteria desired for the automotive body panel.

Table 2.1 Design requirements for a natural FML for automotive body panels

Model	Design requirements
Function	Automotive body panel
Objective	Better performance: high strength, stiffness Lightweight, Lower price
Constraints	Biodegradable
Free variables	Shape and size of component, choice of materials, and orientation of natural fibre reinforcement

Step 1: Problem Statement

As the number of vehicles on roads increases, the CO^2 gas emissions from fuel combustion have also been continuously increasing. One of the ways that has attracted the most attention towards reducing CO^2 emissions is the weight reduction of vehicles.

Step 2: Objective Functions

The objective functions for the design of natural FMLs as automotive body panels are: strong, stiff and lightweight material at a reasonable price. Equations 1 and 2 were considered in the selection of the material. Where E is Young's modulus, ρ is density, C is constant and σ is yield strength.

$$\log E = 3\log\rho + \log C \quad (1)$$

$$\log\sigma = 2\log\rho + \log C \quad (2)$$

Step 3: Objective Constraints
In determining the strength, stiffness and weight of the material, the environmental conditions also had to be taken into consideration. Therefore, the objective constraints which needed to be observed were that the material should be easily available, non-toxic and biodegradable.

Step 4: Implementation
The process involved the selection of the natural fibre that would be used as the fibre-reinforced composite layering to fabricate the natural FML. Since the fabrication of the FMLs involved natural fibre, therefore, the maximum service temperature of the natural fibre also had to be taken into consideration. The maximum service temperature was limited to below 200°C to avoid degradation of the natural fibre 200°C.

2.2 Pugh method

Pugh method is an effective approach for comparing concepts that are not refined enough for direct comparison. The Pugh method needs two tables to set up the datum, namely, a table for the data, and another table for the analysis. A few symbols are used to indicate the comparison with the datum, namely, the equal sign (=) for equalities, the positive sign (+) for better, and the negative sign (-) for less. The end of the row in the table indicates the total number of positive signs (+) for each material. The candidate with the most number of positive signs (+) will be selected as the final material.

3. RESULTS AND DISCUSSION

3.1 Selection of natural fibre for FML

The material was selected from the material universe (all materials) based on the database in the software to avoid a biased selection. As the candidates comprised all materials, the materials were limited to biodegradable which is the constraint of the design requirement as stated in Table 2.1.

The materials will be rank with regard to the objective functions, where the materials were ranked according to the Young’s modulus (E) against the density (ρ), and the yield strength against density, respectively to find the material with the highest stiffness and strength. Materials were sorted using the performance indices line known as the slope constraints. The logarithmic forms of the slope were expressed as straight lines, which were for the Young’s modulus against the density and yield strength against the density, as in Equations (1) and (2). The materials that lay above the slope line had a better performance compared to the materials below the line. The plotted graphs are shown in Figures 3.1, 3.2 and 3.3.

To select the materials that fulfilled the objective functions of a lower price with better performance, charts were plotted of the specific stiffness and specific strength against the price, as shown in Figures 3.4 and 3.5.

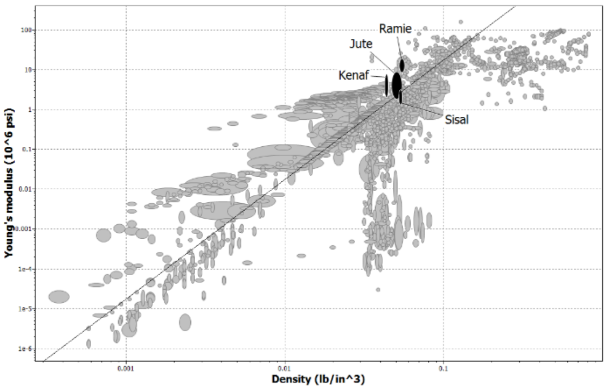

Figure 3.1 Young’s Modulus against Density

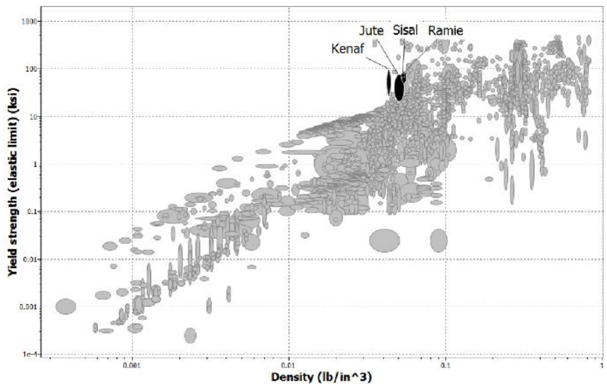

Figure 3.2 Yield Strength against Density

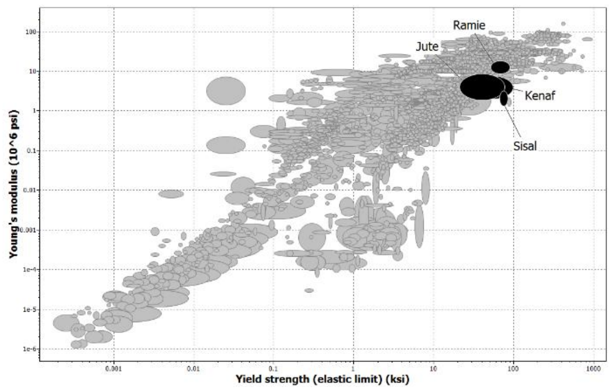

Figure 3.3 Specific Stiffness against Specific Strength

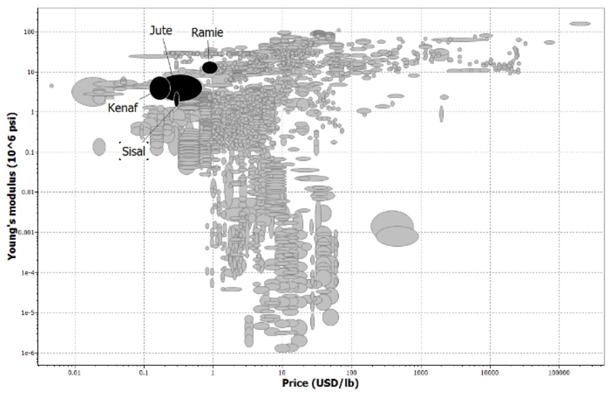

Figure 3.4 Specific Stiffness against Price

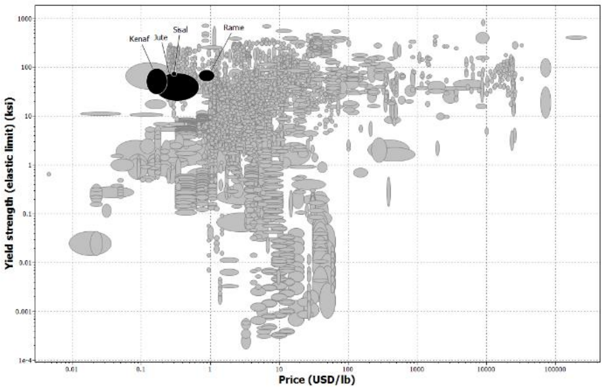

Figure 3.5 Specific Strength against Price

3.2 Comparison Using Pugh Method

Based on the results, kenaf, jute, and ramie were nominated as suitable natural fibres for the fabrication of natural FMLs for automotive body panels. To select the best material for the natural FMLs, the result from the CES was used to compare and justify with steel using the Pugh method. The range of data on the properties was taken from the CES database. Table 3.1 shows the general properties of the nominated natural fibre and Table 3.2 showed the comparison using Pugh method.

Table 3.1 General properties of natural fibres for material selection

General properties	Steel	Kenaf	Jute	Sisal	Ramie
Density (kg/m³)	7800-7900	1190-1200	1300-1500	1444-1500	1450-1550
Price (MYR/ kg)	3.8-4.18	0.811 -1.61	1.09-4.68	2.42-2.83	4.68-7.79
Young's modulus (MPa)	200-221	14-53	13-60	9.4-22	61.4-128
Yield strength (MPa)	476-525	195-666	145-530	460-576	360-612

Table 3.2 Selection of natural fibre material using Pugh method

General properties	Steel	Kenaf	Jute	Sisal	Ramie
Density (kg/m³)	DATUM	+	+	+	+
Price (MYR/kg)		+	+	+	-
Young's modulus (MPa)		-	-	-	-
Yield strength (MPa)		-	-	-	-
Total		+2	+2	+2	+1

Table 3.2 shows that kenaf, jute and sisal fibres have the highest scores. However, based on the general properties in Table 3.1, kenaf fibre had better yield strength, lowest price and density which is 195-666 MPa, RM0.811-RM1.61 per kg and 1190-1200kg/m^3 respectively, which was better than jute and sisal. Therefore, based on the analysis, kenaf fibre was selected as a suitable natural fibre for the fabrication of natural FMLs panels, having satisfied the objective of this study.

4. CONCLUSION

Selection of a suitable natural fibre was identified using the CES and compared using Pugh method based on the design requirements of natural FMLs for use in automotive body panels. Through the comparison judgement kenaf fibre was selected as suitable materials for the fabrication of natural FMLs for automotive body panels which could contribute to the weight reduction of the vehicles.

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