International Review of Mechanical Engineering (I.RE.M.E.), Vol. 16, N. 6
ISSN 1970 - 8734 June 2022

Product Development Using Bio-Reinforced Polymer Matrix Composites for Car Bumper Beam

Nanang Fatchurrohman[1], N. N. N. Nik Mat[2], Mutiara Yetrina[1], Zuhairah Zulkfli[2], Jufriadif Na'am[3]

Abstract – *Product development of a car bumper beam is a critical activity since it is important in order to reduce an impact during a car collision. Currently, most of the production of the bumper beam is manufactured using existing materials such as aluminium. This material has the potential to be replaced with a more environmentally friendly material, which is the bio-reinforced polymer matrix composites. However, engineers are facing problems during the selection of materials selection to form these composites due to properties variations and muti-combinations of materials. In order to overcome this problem, Quality Function Deployment (QFD), Analytic Hierarchy Process (AHP), and Finite Element Analysis (FEA) have been combined to perform the material selection. The objective of this paper is to obtain the best bio-reinforced polymer matrix composites for the application of a car bumper beam. The result has indicated that the flax reinforced polypropylene (Flax+PP) has been the best material obtaining the best normalized score of 0.387, followed by kenaf reinforced polypropylene (0.335), and sisal reinforced polypropylene (0.122).* ***Copyright © 2022 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Product Development, Car Bumper Beam, Bio-reinforced Polymer Matrix Composites, Natural Fibre, Polymer, Quality Function Deployment, Analytic Hierarchy Process, Finite Element Analysis*

Nomenclature

λ_{max}	Maximum or principal eigenvalue
AHP	Analytic Hierarchy Process
a_j	Importance of the product requirement
a_{ij}	Numerical equivalent comparison of *i* and *j*
c_i	Score for the importance of the customer requirements with respect to the importance of the product requirement
CI	Consistency Index
CR	Consistency Ratio
FEA	Finite Element Analysis
HoQ	House of Quality
n	Dimension of matrix
N	Number of criteria
PP	Polypropylene
QFD	Quality Function Deployment
R_{ij}	Importance of the customer requirement
RI	Random Index of the same order matrix
W_i	Calculated priorities

I. Introduction

Currently, some researchers are focusing on substituting new materials for various engineering components with renewable materials such as bio-reinforced composite materials. Bio-reinforced polymer matrix composite materials have used natural fibres as reinforcement. This material has recently attracted the attention of researchers and practitioners because of its benefits over other traditional materials. They are more environmentally friendly, non-hazardous, non-abrasive, renewable, cheap, and have low density. They have been used in transportation, military applications, building and construction industries, packaging, and automotive components including car bumper beams [1]-[6].

Nowadays, one sector that can provide a very large impact on the economy is the automotive sector. It is not only important to the economy but it also promotes the country's image. Progress in an industrial field enables the country to compete with countries around the world.

A car bumper beam is a safety system that is intended to avoid or reduce physical damage. The structure is attached to the front and rear of a vehicle to absorb impact in a collision, the dissipation of energy in a state of high-speed impact, and aerodynamic purpose. An improved bumper beam with improved crashworthiness can be designed. Crashworthiness is the ability of the bumper beam to prevent the passenger's injuries while minimizing the impact force during the collision [2], [3].

The material that is most commonly used for making conventional car bumper beam is aluminium. It is the second most widely used metal in the world after iron. It has a low density and therefore low weight, and high strength. The selection of materials is essential in product development in order to obtain good quality in the production of a car bumper beam. Each material has its characteristics, advantages, and limitations to form a very useful thing. All of these factors affect the selection of a good material choice in the production of a car bumper

https://doi.org/10.15866/ireme.v16i6.22193

beam. This research also considers the physical, the mechanical, and the environmental value of the material that has been selected. In selection material for car bumper beam, the customer prefers a car bumper beam that is light in weight. The primary reason for material selection in the automotive industry is weight reduction.

Thus, selecting material that enables the reduction of the weight of a vehicle is very important. Moreover, the lightweight car bumper beam can less the energy used [7]. Cost plays a very important role in determining the best materials because it faces severe competition in the market. The cost of raw materials is considered a key factor to determine the most suitable material. Therefore, many industries in production already use natural fibre to replace the material. Therefore, these selected materials are very worthwhile to reduce costs. Performance can be defined as the ability of a car bumper beam to stay intact or rigid at high-speed impact and prevent damage to the body of the car in minor impacts. The bumper system should be designed to achieve better performance [8].

The material properties that are related to this factor are flexural strength and flexural modulus. The safety factor is required to bring the structure of the material durable and safe to use in addition to withstand impact during collisions occur. The safety factor also known as the safety factor used to provide design margin exceeds the design capacity of a theory to allow uncertainty in the design process. The safety factor is related to the lack of confidence in the design process. The selection of the appropriate factor of safety also used in the design of car bumper beam is essentially a compromise between the associated additional cost and weight and the benefit of increased safety or reliability. Generally, an increased factor of safety results from a heavier component or a component made from different material [9]. Due to increasing environmental demands especially on dealing with products end of life phase, it is important to select the material easy to be recycled and treated for a better environment. Therefore, disposal and recyclability are the aspects that can be considered in these factors. This factor is also important in the selection of materials based on natural fibres that have been selected. Availability of materials means the existence of raw materials in manufacturing [10]. Besides, it also means that the material to be used is easy to get in future for the development of car bumper beam. New designs of car bumpers may utilize bio-reinforced polymer matrix composite as a substitute for the current material, which is aluminium. The reinforcement fibres provide strength and stiffness and are influenced by the natural properties of these fibres. Natural-based fibres such as hemp, kenaf, flax, jute, coir, banana and sisal [3] have increased marketable benefits in automotive industries. The benefits of natural fibres over synthetic fibres such as glass or carbon are cost-effective, low density, carbon dioxide blockade, ease of breakage and bio-degradability [4]. Furthermore, bio-composites are recyclable, breakage resistant, have sufficient energy requirements [11], have heat insulation properties and acoustic properties, and are safer for health [12]. Bio-composite materials also offer higher specific strength, modulus, and damping capability [13]. When the composite materials are applied, the weight of the vehicle is decreased by 34% as well as the noise and vibration were reduced [14]. Hydrophilic properties of natural fibres cause poor fibre-matrix interfacial adhesion, which is comparable with compatibility between fibres and matrix materials [15]. Thus, natural fibres can be surface treated to improve their adhesion and enhance mechanical properties. However, only some plant fibres are suitable for automotive applications [16], [17]. Natural fibre composites are claimed to offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and end of life biodegradability of components. Since, such superior environmental performance is an important driver of increased future use of natural fibre composites, a thorough comprehensive analysis of the relative environmental impacts of natural fibre composites and conventional composites, covering the entire life cycle, is warranted.

The industries based on the utilization of natural fibre and polymers are striving for excellence and have bright prospects, driven mainly by the environmental concerns of using a renewable resource [18]. The ultimate goal for these attempts in research and development is to pay a way to procure and inculcate this advanced material with optimum technical performance and full biodegradability. Natural fibre reinforced polypropylene (PP) based bio-composites are widely investigated to contend with non-renewable petroleum-based components. The kind of fibre used has a significant role in fibre or matrix adhesion and thereby affects the mechanical performance of the bio-composites [19]-[21].

Reinforcement is the secondary phase in composite materials that are embedded in the matrix. Reinforcement serves to give strength and stiffness to the composite material. It should be tougher than matrix materials to resist the load that will force on it and it should be also capable to give benefits to composite materials [20], [22]-[24]. Bio-reinforced polymer matrix composite is a composite material formed by a combination of a reinforcement and polymer matrix. The matrix is provided in a bulk form to hold the embedded materials known as fibre-reinforced composite materials. The matrix in composites holds the fibres together and protects them from mechanical or environmental damage as well as failure. It also provides a better surface finish and functionality and it transfers applied loads to those fibres during their application. The matrix is composed of thermoplastic or thermoset polymers such as polyethene and unsaturated polyester. Polypropylene (PP) is commonly used as matrix polymers that will be reinforced with natural fibre, which has some advantages including strength, good corrosion, weather-resistant, lightweight and cost-effectiveness. The low weight and the good mechanical properties of PP have made it an ideal material in the automotive industry [19], [25].

Engineers should find a material that has high environmental factors like sustainability, recyclability, biodegradability, low hazard level, less pollution and disposal factor [26]. The industries and the governments are working together, and have come up with solutions that are essential for the green recovery of world economies. [27] Bio-reinforced polymer matrix composites are potential materials that can benefit social, environmental, and economic factors, hence contributing to sustainability. This study covers the selection of materials using a polymer with natural fibre for car bumper beam and also validates the simulation based on the selected material according to the product performance. This study aims to investigate the applications of bio-reinforced polymer matrix composites for a car bumper beam. Polypropylene (PP) matrices are combined with various natural fibres to form the composite system. The first work is to collect a bio-reinforced PP composite database. Secondly, the Quality Function Deployment (QFD) and the Analytic Hierarchy Process (AHP) methods are used for the selection of the best material for car bumper beam. Lastly, it is validated using Finite Element Analysis (FEA) for the best-selected material.

This paper is organized and developed by initially reviewing related works in the introduction section. It is followed by the methodology, which covers the procedure to conduct the research. The next section explains in detail the results and the discussion of the product development work. Finally, the paper ends with the conclusion of the overall study.

II. Methodology

The first method involved has been Quality Function Deployment (QFD). This method has been used to relate the customer requirements and technical product requirements during the product development process [28], [30]. The QFD tool used in this study is the House of Quality (HoQ). This method is a matrix of an iterative process. It is used to determine and rank the important parameters of the bumper beam. In order to proceed with HoQ, information according to customer requirements, which are known as the Voice of Customer (VoC), has been collected.

After collecting and analysing sufficient information, the important criteria of the bumper beam because of customer requirements will be listed and put into HoQ.

Next, a ranking of the customer requirements is carried out based on their priorities and preference. A scale of 1-5 is used to allocate the score for the customer requirements respected to the product requirements.

Meanwhile, the correlation between the product requirements will be done at the roof matrix. The correlation between the technical requirements with a positive implication is assigned with (+), whereas technical requirements' negative implication is assigned with (-), and blank for no implication. The last step of the HoQ has been to determine the weight for technical requirements. Then the technical importance is calculated by using equation (1), where a_j is the technical importance of each product requirement, R_{ij} is the importance of each customer requirement, and c_i is the score for the customer requirements with respect to the product requirement:

$$a_j = \sum_{i=1}^{n} R_{ij}\, c_i \quad (1)$$

The AHP is a multi-criteria decision-making tool and it has been intended to analyse the main criteria, the sub-criteria, and the alternatives to achieve the goal. First, a hierarchy framework is developed. Then, pair-wise comparison matrices are constructed. The pair-wise comparison matrix presents the relative importance of the factors at the current level with respect to factors at a higher level. Next, the pair-wise comparison is synthesized. This involves the assessment of the vectors of priorities and overall priority [28], [29]. The priorities (W_i) can be calculated by using Equation (2):

$$W_i = \frac{1}{n}\sum_{j=1}^{n} \frac{a_{ij}}{\sum_i^n a_{ij}}, \qquad i, j = 1,2 \ldots n \quad (2)$$

a_{ij} is the numerical equivalent comparison of i and j, N is the number of criteria. After that, consistency is evaluated. The Consistency Ratio (CR) is used to estimate the consistency of the judgments among the pair-wise comparisons:

$$CR = \frac{CI}{RI} \quad (3)$$

where RI is the random index of the same order matrix and CI is the consistency index, which is defined as:

$$CI = \frac{\lambda_{\max}}{n-1} \quad (4)$$

where λ_{max} represents the maximum or principal eigenvalue of the pair-wise comparison matrix and n represents the size of the matrix. The closer λ_{max} is to n the more consistent the judgment matrix. If the CR is less than 0.1, the judgment matrix is consistent and acceptable.

However, if CR is greater than 0.1, the judgment matrix is inconsistent. A revised and improvement of judgments should be carried out to obtain a consistent matrix. Lastly, the best design concept has been selected based on the highest value of priority of the results. In this study, four levels of hierarchy diagrams have been constructed to show the connection between all the levels (Fig. 1). The AHP diagram can be visualized as a diagram with the goal at the top, the seven criteria, and ten sub-criteria in between followed by five alternatives at the bottom.

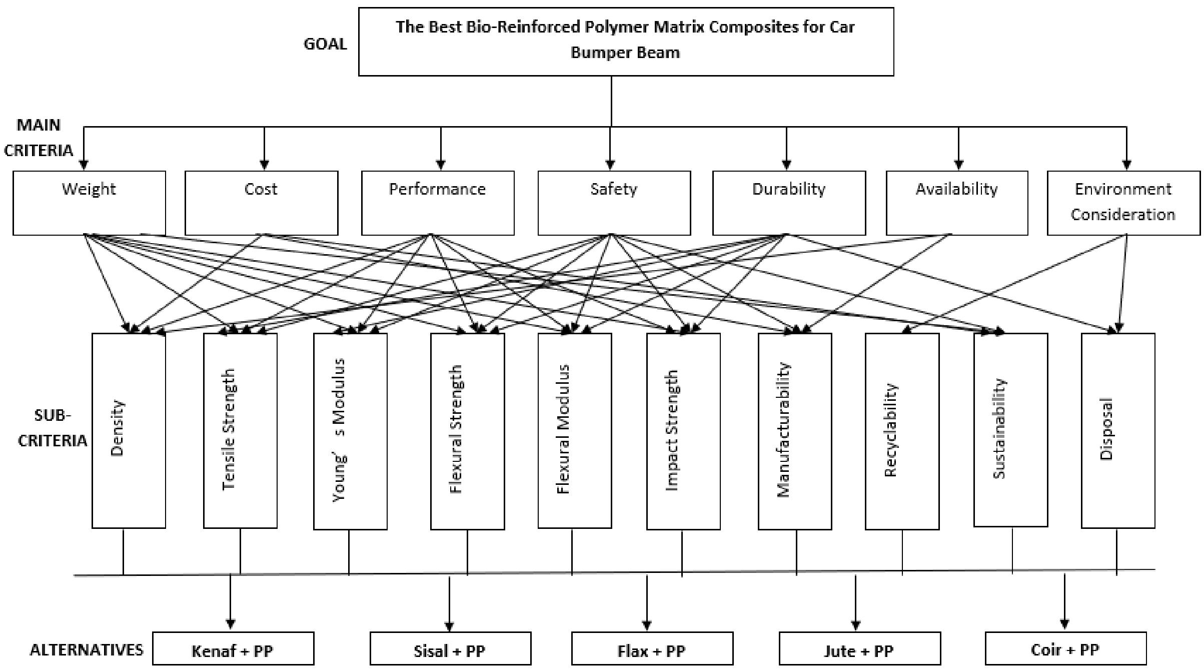

Fig. 1. Four levels of the AHP

The goal has been clearly stated to identify factors or criteria affecting the selection process. After determining the factors for each level, the hierarchical structure has been formed to view the relationships among the overall goal, criteria, sub-criteria and also alternatives. The AHP diagram has been reconstructed and analysed using Super Decision software. The AHP has been applied for the selection of the best bio-reinforced polymer matrix composites for a car bumper beam. In this study, Finite Element Analysis (FEA) has been used to validate the best material selected. ANSYS has been used to perform FEA in a virtual environment and to solve potential performance issues.

The design of the car bumper beam has been drawn using CATIA software. The accuracy of the FEA simulation also depends on how accurately the model of the car bumper beam is. Fig. 2 and Fig. 3 show the design of the car bumper beam from the front and back views, respectively. FEA has used a mathematical model and has numerically solved complex structural problems [31], [32]. This method is suitable to analyse and evaluate the structural analysis. FEA has been used to find total deformation, stress and strain.

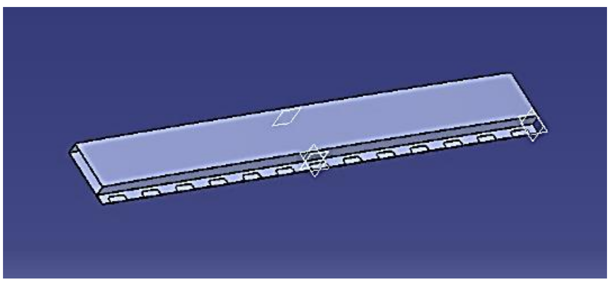

Fig. 2. The design of car bumper beam using CATIA software – front view

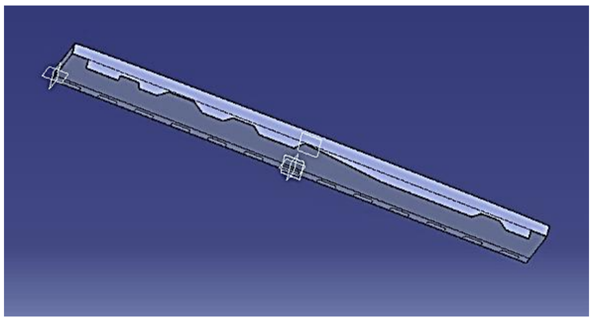

Fig. 3. The design of car bumper beam using CATIA software – back view

III. Results and Discussion

The process of constructing the HoQ has been based on various sources related to car bumper beams. The HoQ has been used to determine the relationship between the customer requirement and the product requirement.

From the HoQ the technical importance of each product means that the bumper beam's most important features are light and strong.

Then it is followed by the flexural strength and flexural modulus. The density and the tensile strength of the material have the highest values (69), followed by flexural strength and flexural modulus (64). This indicates that the properties have been mostly defined by density and tensile strength. The values assigned to the technical importance increase the consistency and accuracy of the AHP. This has included structuring a wide range of criteria into a hierarchy and the relative importance of each criterion is then used for the next phase of the investigation. The result of the HoQ analysis is presented in Fig. 4.

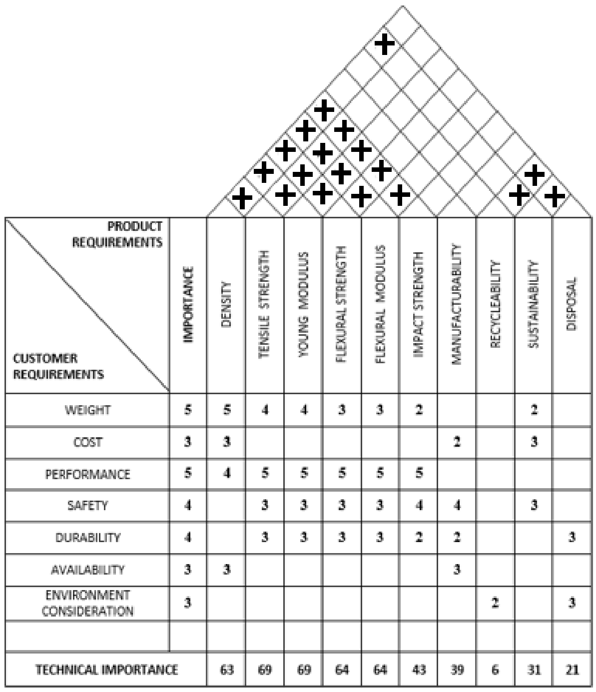

Fig. 4. HoQ Matrix

The final phase of the study is the implementation of AHP as the multi-criteria decision-making to select the best material for the car bumper beam. It is executed by using weighted scoring and organizing priorities. SUPER DECISIONS software has been used to carry out the AHP. Table I compares the density, the tensile strength, the young modulus, the flexural strength, the manufacturability, the recyclability, the sustainability, and the disposal of all the material alternatives involved in the selection. This would enable the pair-wise comparison to be carried out easier. This process has involved comparing and assessing the relative importance of the criteria, comparing alternatives requirements for each criterion. Then it is followed by determining the overall position of the alternative. This method has the advantage of achieving high-quality products and shortening the product development process. Moreover, AHP helps to identify the objective and subjective measures by providing a useful mechanism to check the consistency [21], [22].

Fig. 5 shows the result of node comparison for impact strength and the ranking of node comparison for impact strength at the sub-criteria level. It shows that flax reinforced polypropylene (Flax+PP) has the highest ranking with 0.53666 followed by kenaf reinforced polypropylene (Kenaf+PP) with 0.29450 while jute reinforced polypropylene (Jute+PP) has the lowest ranking with 0.03279 compared to others. The impact strength of the material is important to protect the passenger when a collision occurred. Fig. 6 shows the result and the ranking of node comparison for tensile strength at the sub-criteria level. It shows that Flax+PP has the highest ranking with 0.56299 while coir reinforced polypropylene (Coir+PP) has the lowest ranking with 0.03686. The tensile strength of a material is the maximum amount of tensile stress that it can take before failure. Fig. 7 shows the result and the ranking of node comparison for flexural strength at the sub-criteria level. It shows that Flax+PP has the highest ranking with 0.61392 whereas Coir+PP has the lowest ranking with 0.02726. The flexural strength of a material is defined as its ability to resist deformation under load. It is also known as modulus of rupture, bend strength, or fracture strength. Fig. 8 shows the result and the ranking of node comparison for manufacturability at the sub-criteria level. It shows that Flax+PP has the highest ranking with 0.35917 while Coir+PP has the lowest ranking with 0.09441. The manufacturability of the material is the general engineering art of designing a car bumper beam in such an easy way to manufacture.

TABLE I
PROPERTIES OF THE BIO-REINFORCED COMPOSITES

Fiber	Matrix	Density (g/cm^3)	Tensile Strength (MPa)	Young Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Impact Strength (kJ/m^3)	Manufacturability	Recyclability	Sustainability	Disposal
Kenaf	PP	1.48	50	8.3	59	7.6	32	0.50	0.7	0.88	1
Sisal	PP	1.33	55	4.8	52	4.5	28	0.30	0.6	0.47	1
Flax	PP	1.4	67	6.7	63	6.3	44	0.90	0.9	0.65	1
Jute	PP	1.46	36	4.6	36	4.6	18.4	0.20	0.3	0.33	1
Coir	PP	1.21	35.9	1.9	27.24	1.15	28.1	0.05	0.1	0.25	1

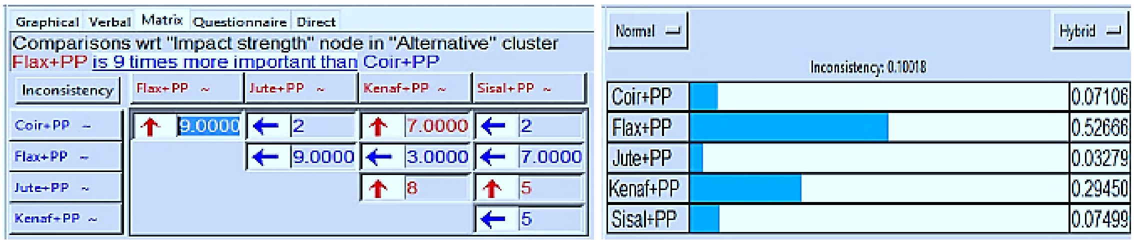

Fig. 5. Pair-wise comparison and relative priority of impact strength among the five alternatives material selection of car bumper beam

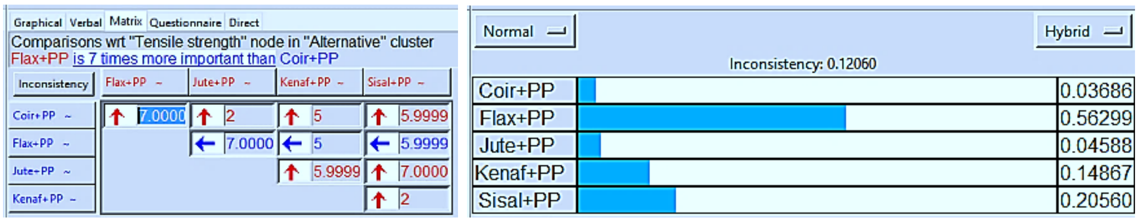

Fig. 6. Pair-wise comparison and relative priority of tensile strength among the five alternatives material selection of car bumper beam

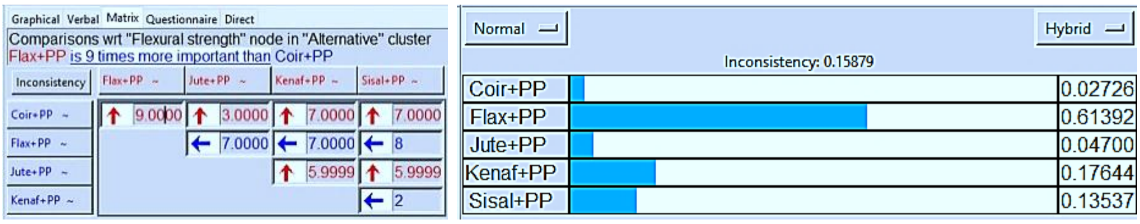

Fig. 7. Pair-wise comparison and relative priority of flexural strength among the five alternatives material selection of car bumper beam

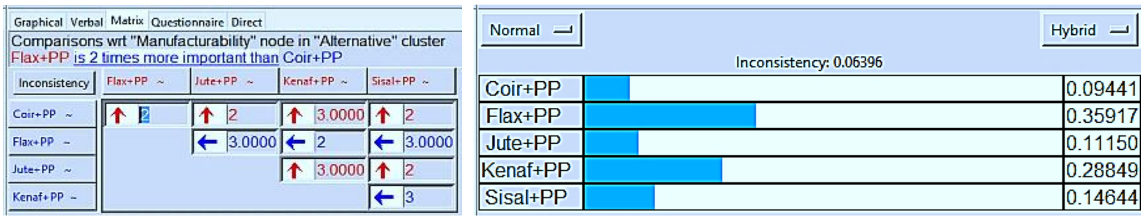

Fig. 8. Pair-wise comparison and relative priority of manufacturability among the five alternatives material selection of car bumper beam

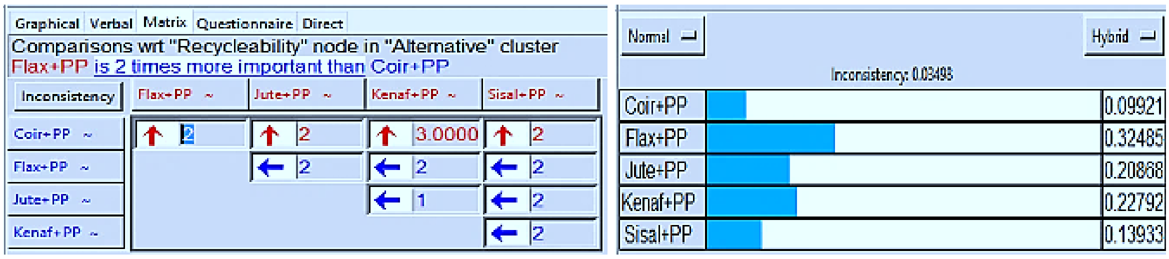

Fig. 9. Pair-wise comparison and relative priority of recyclability among the five alternatives material selection of car bumper beam

Fig. 9 shows the result and the ranking of node comparison for recyclability at the sub-criteria level. It shows that Flax+PP has the highest ranking with 0.32485 while Coir+PP has the lowest ranking with 0.09921.

Materials that can be recycled will reduce the need for new materials to be produced.

The lower energy required to reconstitute materials is compared to the amount of energy required for new production. Fig. 10 shows the overall ranking for the pair-wise connection. This figure shows the overall ranking for the pair-wise connection which reveals that Flax+PP with the normalised score of 0.387, followed by Kenaf+PP (0.335) and Sial+PP (0.122) is the most appropriate alternative material for car bumper beam. In physical and mechanical properties of the combination table, it also shows that Flax+PP have values in impact strength = 44 kJ/m^3, tensile strength = 67 MPa and flexural strength = 63 MPa.

Name	Graphic	Ideals	Normals	Raw
Coir+PP		0.155213	0.060123	0.020041
Flax+PP		1.000000	0.387358	0.129119
Jute+PP		0.246220	0.095375	0.031792
Kenaf+PP		0.864012	0.334682	0.111561
Sisal+PP		0.316145	0.122461	0.040820

Fig. 10. Relative priority in selecting the best material for car bumper beam among the five alternatives concerning the main criteria and sub-criteria

A sensitivity analysis has been performed to show the effect of alternatives using different parameters of the car bumper beam model. Sensitivity analysis has been also performed to see how the ranking of alternative materials varies by changing the priority of the main criteria.

Hence, this step has been important to observe how the materials respond to any changes in the listed criteria.

First, the value of performance is increased to 90% of the main goal and the remaining 10%. It is observed in Fig. 11 that the best choice is Flax+PP. This proves that although the weight of performance has been subjected to an unexpected change under normal conditions, the best choice remains and none of the alternatives has become dominant in the framework.

The material has not been sensitive to a small change in the weight of performance.

After that, the cost of materials has been increased to 90% with respect to the main goal and the remaining 10% to see the effect on the choices of material. The results in Fig. 12 show that Flax+PP has been also the most cost-effective. Next, the same analysis has been applied to the criteria of the weight of the material. In this case, the best material is Flax+PP as shown in Fig. 13. The same conclusion can be made for the safety criteria where this material has not been sensitive to changes in the weight of safety (Fig. 14).

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: AHP.sdmod

Name	Graphic	Ideals	Normals	Raw
Coir+PP		0.048627	0.031913	0.015957
Flax+PP		1.000000	0.656284	0.328142
Jute+PP		0.061472	0.040343	0.020172
Kenaf+PP		0.334471	0.219508	0.109754
Sisal+PP		0.079159	0.051951	0.025975

Fig. 11. Sensitivity analysis of performance

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: AHP.sdmod

Name	Graphic	Ideals	Normals	Raw
Coir+PP		0.069645	0.044151	0.022075
Flax+PP		1.000000	0.633940	0.316970
Jute+PP		0.114446	0.072552	0.036276
Kenaf+PP		0.313963	0.199034	0.099517
Sisal+PP		0.079383	0.050324	0.025162

Fig. 12. Sensitivity analysis of cost

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: Unnamed file 0

Name	Graphic	Ideals	Normals	Raw
Coir+PP		0.063593	0.041912	0.020956
Flax+PP		1.000000	0.659059	0.329529
Jute+PP		0.086473	0.056991	0.028496
Kenaf+PP		0.251348	0.165653	0.082827
Sisal+PP		0.115900	0.076385	0.038192

Fig. 13. Sensitivity analysis of weight

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: AHP.sdmod: ratings

Name	Graphic	Ideals	Normals	Raw
Coir+PP		0.237547	0.116454	0.058227
Flax+PP		1.000000	0.490237	0.245119
Jute+PP		0.288535	0.141451	0.070725
Kenaf+PP		0.184314	0.090358	0.045179
Sisal+PP		0.329432	0.161500	0.080750

Fig. 14. Sensitivity analysis of durability

A similar analysis has been performed for the durability factor. The weight of the durability factor has been subjected to 90% and leaving 10% for other criteria to share equally. In this condition, the priority results shown in Fig. 15 have listed that Flax+PP remains the best material.

Another similar analysis has been performed for the availability factor. The weight of the availability factor has been subjected to 90% and leaving 10% for other criteria to share equally. In this condition, the priority results shown in Fig. 16 have ranked Flax+PP as the best available material.

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: AHP.sdmod

Name	Graphic	Ideals	Normals	Raw
Coir+PP		0.262236	0.123058	0.061529
Flax+PP		1.000000	0.469263	0.234632
Jute+PP		0.275595	0.129326	0.064663
Kenaf+PP		0.382542	0.179513	0.089756
Sisal+PP		0.210628	0.098840	0.049420

Fig. 15. Sensitivity analysis of availability

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: AHP.sdmod

Name	Graphic	Ideals	Normals	Raw
Coir+PP		0.116386	0.070717	0.035359
Flax+PP		1.000000	0.607610	0.303805
Jute+PP		0.062659	0.038072	0.019036
Kenaf+PP		0.371856	0.225943	0.112972
Sisal+PP		0.094893	0.057658	0.028829

Fig. 16. Sensitivity analysis of recycling and life cycle consideration

Finally, the same analysis has been held for environment consideration criteria. A similar conclusion can be made for the environment consideration criteria where Flax+PP has stayed as it is, i.e. a recyclable material and has a longer life cycle compared to others as illustrated in Fig. 19. To summarise, the sensitivity analysis has been performed and it has showed in the decision-making has been consistent. Although some significant changes have been made to the criteria weights, Flax+PP has turned out to be the best alternative material for a car bumper beam in all the criteria. The validation process implemented FEA as the methodology. The design of the car bumper beam is meshed for structural analysis. Structural analysis has been used to find the total deformation, stress and strain.

A force of 180.560 kN has been applied to the bumper. The best new alternative material, which is Flax+ PP, had been selected and compared to the existing material, which is aluminium. The material properties used in the simulation are depicted in Table II. The mechanical properties of aluminium have been applied to get the results for structural analysis simulation for car bumper beam using this material. The result for the total deformation of aluminium is shown in Fig. 17. Fig. 18 illustrates the result of maximum and minimum stress.

Whereas, Fig. 19 presents the result of maximum and minimum strain for aluminium.

TABLE II
PROPERTIES OF MATERIAL

Material	Density (kg/m^3)	Tensile Strength (MPa)	Young Modulus (GPa)	Poisson's Ratio
Aluminium	2700	70	6.8	0.33
Flax+PP	1400	67	6.7	0.35

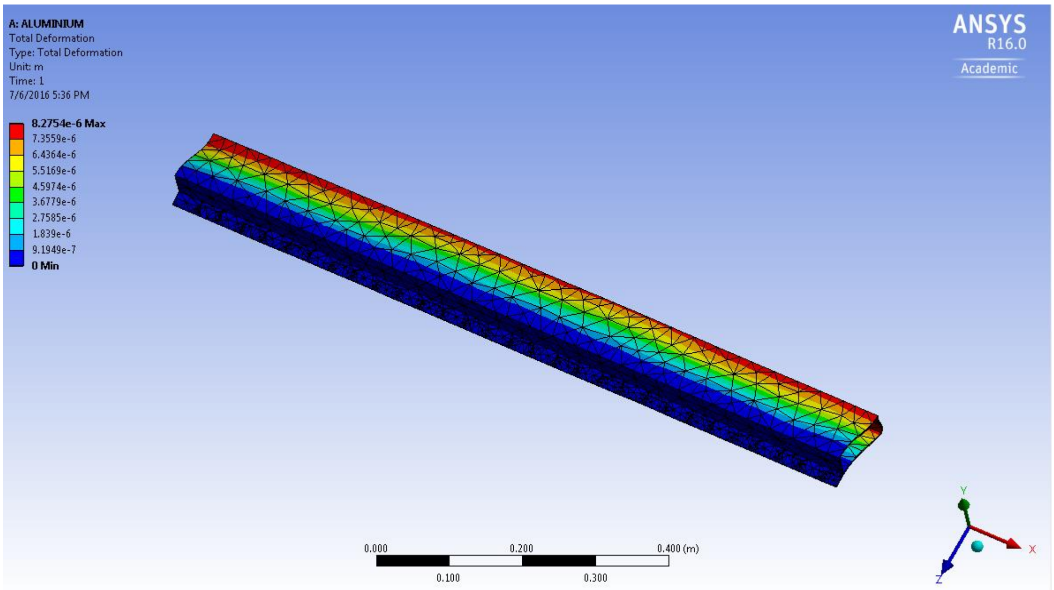

Fig. 17. The deformation of aluminium

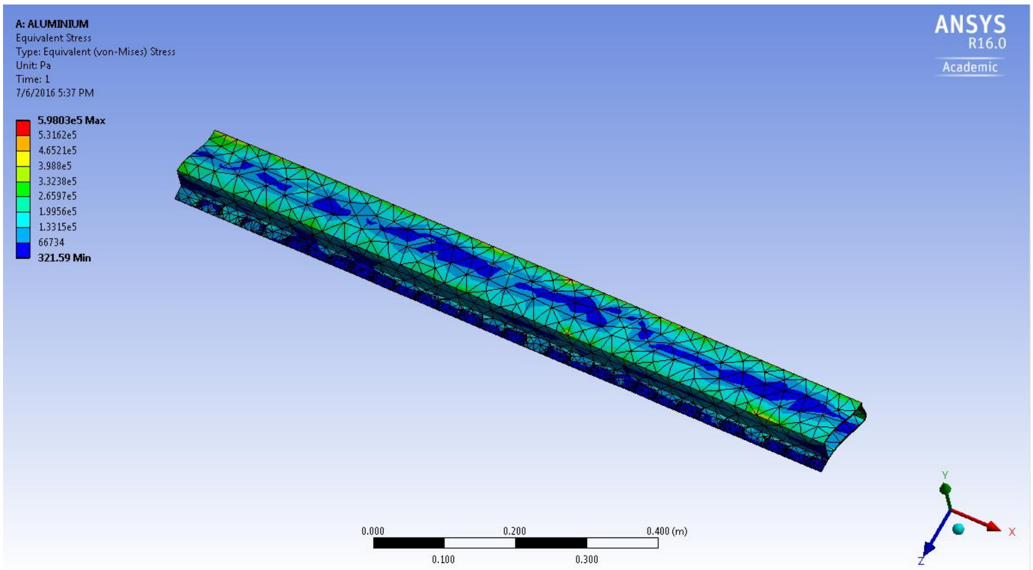

Fig. 18. The maximum and minimum stress of aluminium

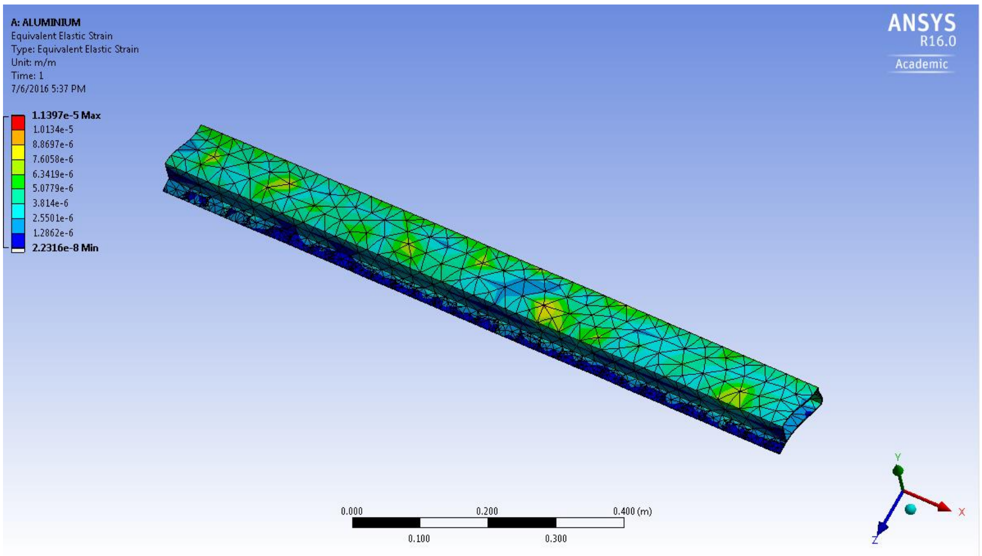

Fig. 19. The maximum and minimum strain of aluminium

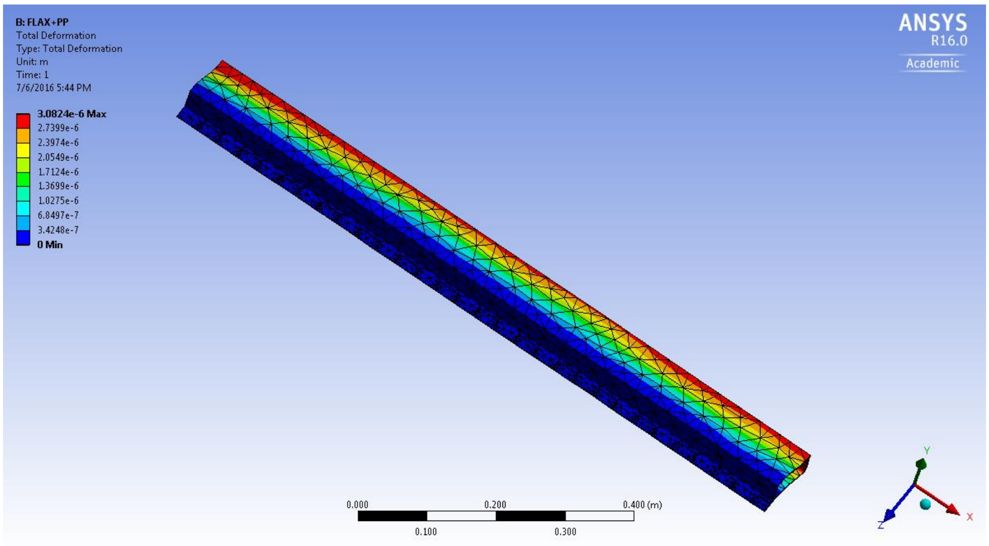

Fig. 20. The deformation of Flax+PP

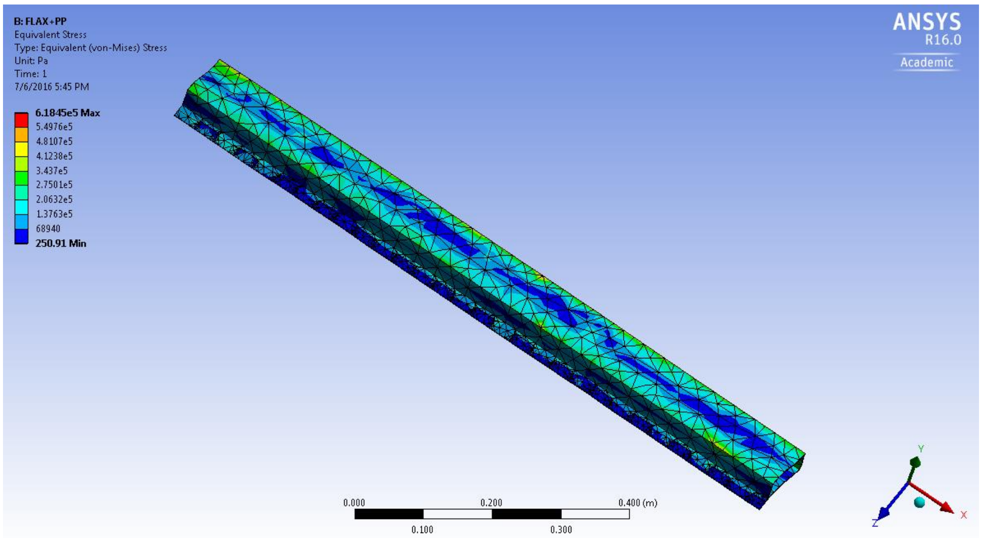

Fig. 21. The maximum and minimum stress of Flax+PP

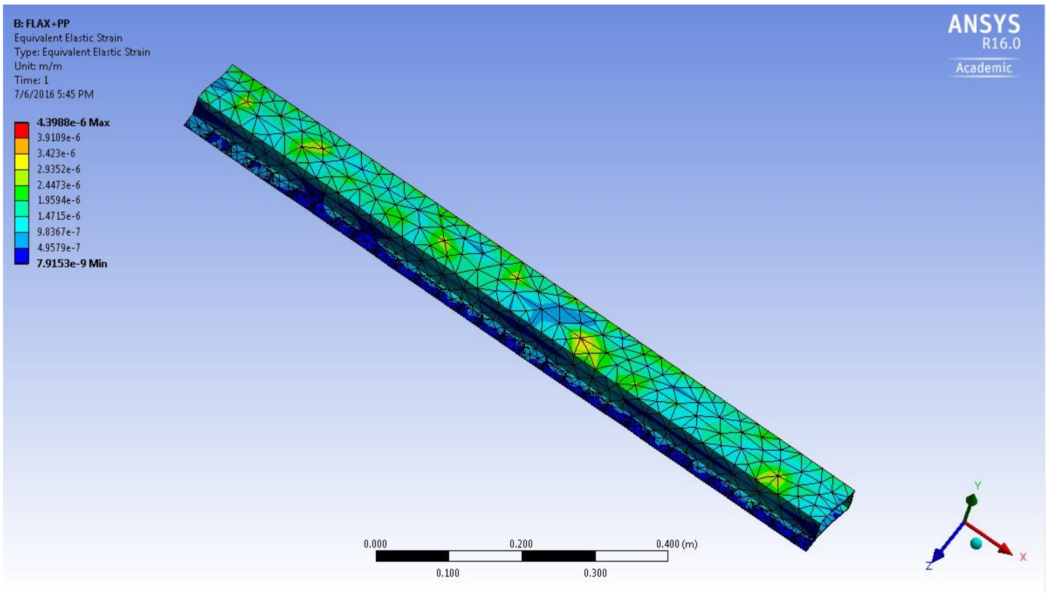

Fig. 22. The maximum and minimum strain of Flax+PP

Fig. 20 shows the result for the total deformation of Flax+PP. Fig. 21 illustrates the result of maximum and minimum stress whereas Fig. 22 presents the result of maximum and minimum strain for Flax+PP. The simulation results have indicated better mechanical performance of Flax+PP compared to aluminium if applied to a car bumper beam. Table III presents the comparison of the FEA results. The deformation of Flax+PP is lower than aluminium, which has proved that Flax+PP has more ability to reduce the impact when a collision occurred. The Flax-PP has been able to withstand higher maximum stress and strain than aluminium. The results show that the new material (Flax+PP) has been better than the existing material (aluminium), which means it is a more preferable material for the production of car bumper beam.

TABLE III
THE COMPARISON OF THE FEA RESULTS

Material	Deformation (mm)	Stress (MPa)		Strain (MPa)	
		Min	Max	Min	Max
Aluminium	8.2754e^{-6}	321.59	5.980e^{5}	2.231e^{-9}	1.139e^{-6}
Flax+PP	3.0824e^{-6}	250.91	6.184e^{5}	7.915e^{-9}	4.398e^{-6}

IV. Conclusion

The main objective of this study has been to find the best material using bio-reinforced polymer matrix composites for car bumper beam application. Quality Function Deployment (QFD), Analytic Hierarchy Process (AHP), and Finite Element Analysis (FEA) have been combined to perform the material selection. The result shows that the flax reinforced polypropylene (Flax+PP) has been the best material obtaining the best-normalised score of 0.387, followed by kenaf reinforced polypropylene (Kenaf+PP) with a score of 0.335, and sisal reinforced polypropylene (Sisal+PP) with a score of 0.122. The validation process indicates that Flax+PP has a better performance compared to the current material, which is aluminium. The new material of the bumper beam could optimise the strength and reduce the weight.

Furthermore, it has increased the possibility of utilising bio-degradable and recyclable materials. This material will help innovate the car's performance as well as preserve environment. The validation will enable the material to be potentially considered in the automotive industry. For future work, the material selected needs to undergo fabrication and experimental testing. Other avenue of study would be to take into account the possibility of using different polymer as the matrix to form the bio-reinforced composites system.

Acknowledgements

This publication was supported by the Research and Community Service or Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM), Universitas Putra Indonesia YPTK Padang, Research Grant or Surat Perjanjian Penelitian No: 7/UPI-YPTK/LPPM/P/KP/IV/2022.

References

[1] P. Chatterjee, S. Chakraborty, Material Selection using Preferential Ranking Methods, *Materials and Design*, 35, pp. 384–393, 2012.

[2] M. M. Davoodi, S. M. Sapuan, A. Aidy, N. A. Osman, A. A. Oshkour, W. W. Abas, Development Process of New Bumper Beam for Passenger Car: A Review, *Materials & Design*, 40, pp. 304–313, 2012.

[3] V. Naik, M. Kumar, A Review on Natural Fiber Composite Material in Automotive Applications, *Engineered Science*, 18, pp. 1-10, 2021.

[4] L. O. Afolabi, P. S. M. Megat-Yusoff, Z. M. Ariff, M. S. Hamizol, Fabrication of Pandanus Tectorius (Screw-Pine) Natural Fiber using Vacuum Resin Infusion for Polymer Composite Application, *Journal of Materials Research and Technology*, 8(3), pp. 3102-3113, 2019.

[5] Kastiawan, I., Sutantra, I., Sutikno, S., Effect of Bottom Ash Treatment and Process Variables on the Strength of

Polypropylene Composites, (2020) *International Review of Mechanical Engineering (IREME)*, 14 (5), pp. 324-330.
doi: https://doi.org/10.15866/ireme.v14i5.18804
[6] Sivakumar, D., Ng, L., Subramaniam, K., Bapokutty, O., Pilvamangalam, N., Ab Ghani, A., Charpy Impact Response of Fibre-Metal Laminates Based on Woven Kenaf/Glass Fibre Reinforced Polypropylene, (2020) *International Journal on Engineering Applications (IREA)*, 8 (2), pp. 58-63.
doi: https://doi.org/10.15866/irea.v8i2.17830
[7] Godara, S. S., & Nagar, S. N. (2020). Analysis of frontal bumper beam of automobile vehicle by using carbon fiber composite material. *Materials Today: Proceedings*, 26, 2601-2607.
[8] Sapuan, S. M., Ilyas, R. A., & Asyraf, M. R. M. (2022). Safety Issues in Transportation Design. *Safety and Health in Composite Industry*, 267-291.
[9] Tisza, M., & Czinege, I. (2018). Comparative study of the application of steels and aluminium in lightweight production of automotive parts. *International Journal of Lightweight Materials and Manufacture*, 1(4), 229-238.
[10] Lotfi, A., Li, H., Dao, D. V., & Prusty, G. (2021). Natural fiber–reinforced composites: A review on material, manufacturing, and machinability. *Journal of Thermoplastic Composite Materials*, 34(2), 238-284.
[11] B. F. Yousif, A. Shalwan, C. W. Chin, K. C. Ming, Flexural Properties of Treated and Untreated Kenaf/Epoxy Composites, *Materials & Design*, 40, pp. 378-385, 2012.
[12] N. Saba, M. T. Paridah, M. Jawaid, Mechanical Properties of Kenaf Fibre Reinforced Polymer Composite: A Review, *Construction and Building Materials*, 76, pp. 87–96, 2015.
[13] S. P. Singaraj, K. P. Aaron, K. Kaliappa, K. Kattaiya, M. Ranganathan, Investigations on Structural, Mechanical and Thermal Properties of Banana Fabrics for Use in Leather Goods Application, *Journal of Natural Fibers*, 18(11), pp. 1618-1628, 2021.
[14] N. Fantuzzi, M. Bacciocchi, D. Benedetti, J. Agnelli, The Use of Sustainable Composites for the Manufacturing of Electric Cars, *Composites Part C: Open Access*, 4, p. 100096, 2021.
[15] H. A. Aisyah , M. T. Paridah , S. M. Sapuan , A. Khalina ,O. B. Berkalp, S. H. Lee, C. H. Lee, N. M. Nurazzi, N. Ramli, M. S. Wahab, and R. A. Ilyas, Thermal Properties of Woven Kenaf/Carbon Fibre-Reinforced Epoxy Hybrid Composite Panels, *International Journal of Polymer Science*, 2019.
[16] P. Chatterjee, S. Chakraborty, Material Selection using Preferential Ranking Methods, *Materials and* Design, 35, pp. 384–393, 2012.
[17] M. M. Davoodi, S. M. Sapuan, A. Aidy, N. A. Osman, A. A. Oshkour, W. W. Abas, Development Process of New Bumper Beam for Passenger Car: A Review, *Materials & Design*, 40, pp. 304–313, 2012.
[18] Raza, S., Zhang, J., Ali, I., Li, X., & Liu, C. (2020). Recent trends in the development of biomass-based polymers from renewable resources and their environmental applications. *Journal of the Taiwan Institute of Chemical Engineers*, 115, 293-303.
[19] V. Naik, M. Kumar, A Review on Natural Fiber Composite Material in Automotive Applications, *Engineered Science*, 18, pp. 1-10, 2021.
[20] L. O. Afolabi, P. S. M. Megat-Yusoff, Z. M. Ariff, M. S. Hamizol, Fabrication of Pandanus Tectorius (Screw-Pine) Natural Fiber using Vacuum Resin Infusion for Polymer Composite Application, *Journal of Materials Research and Technology*, 8(3), pp. 3102-3113, 2019.
[21] B. F. Yousif, A. Shalwan, C. W. Chin, K. C. Ming, Flexural Properties of Treated and Untreated Kenaf/Epoxy Composites, *Materials & Design*, 40, pp. 378-385, 2012.
[22] N. Saba, M. T. Paridah, M. Jawaid, Mechanical Properties of Kenaf Fibre Reinforced Polymer Composite: A Review, *Construction and Building Materials*, 76, pp. 87–96, 2015.
[23] S. P. Singaraj, K. P. Aaron, K. Kaliappa, K. Kattaiya, M. Ranganathan, Investigations on Structural, Mechanical and Thermal Properties of Banana Fabrics for Use in Leather Goods Application, *Journal of Natural Fibers*, 18(11), pp. 1618-1628, 2021.
[24] N. Fantuzzi, M. Bacciocchi, D. Benedetti, J. Agnelli, The Use of Sustainable Composites for the Manufacturing of Electric Cars, *Composites Part C: Open Access*, 4, p. 100096, 2021.
[25] N.N. Ramli, Y. Mazlan, Z. Ando, Z. Leman, K. Abdan, A. A. Aziz, and N. A. Sairy, Natural fiber for green technology in automotive industry: a brief review. *IOP Conference Series: Materials Science and Engineering*, 368(1), p. 012012, IOP Publishing, 2018.
[26] Moshood, T. D., Nawanir, G., Mahmud, F., Mohamad, F., Ahmad, M. H., & AbdulGhani, A. (2022). Sustainability of biodegradable plastics: New problem or solution to solve the global plastic pollution?. *Current Research in Green and Sustainable Chemistry*, 100273.
[27] Bradu, P., Biswas, A., Nair, C., Sreevalsakumar, S., Patil, M., Kannampuzha, S., Mukherjee, A.G., Wanjari, U.R., Renu, K., Vellingiri, B. and Gopalakrishnan, A.V., 2022. Recent advances in green technology and Industrial Revolution 4.0 for a sustainable future. *Environmental Science and Pollution Research*, pp.1-32.
[28] C.D. Marini, N. Fatchurrohman, A. Azhari, and S. Suraya, Product development using QFD, MCDM and the combination of these two methods. *IOP Conference Series: Materials Science and Engineering*, 114(1), p. 012089. IOP Publishing, 2016.
[29] I. Canco, D. Kruja, and T. Iancu, AHP, a Reliable Method for Quality Decision Making: A Case Study in Business. Sustainability, 13(24), p.13932, 2021.
[30] Cardenas, J., Espinel, E., Rojas, J., Failure Analysis Methodology in Industrial Control Valves Using Quality Function, (2020) *International Review of Automatic Control (IREACO)*, 13 (6), pp. 273-282.
doi: https://doi.org/10.15866/ireaco.v13i6.19331
[31] Szabó, F., Szarka, Á., Finite Element Study of Rotating Elements of a Ventilator, (2019) *International Review of Mechanical Engineering (IREME)*, 13 (6), pp. 326-331.
doi: https://doi.org/10.15866/ireme.v13i6.17145
[32] Marcalikova, Z., Sucharda, O., Modeling of Fiber-Reinforced Concrete and Finite Element Method, (2021) *International Review of Civil Engineering (IRECE)*, 12 (1), pp. 11-19.
doi: https://doi.org/10.15866/irece.v12i1.18636

Authors' information

[1]Faculty of Engineering, Universitas Putra Indonesia YPTK, Padang 25221, Indonesia.

[2]Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

[3]Universitas Putra Indonesia YPTK, Padang 25221, Indonesia.

Nanang Fatchurrohman (Corresponding Author) is a senior lecturer at the Faculty of Engineering, Universitas Putra Indonesia YPTK Padang. He has bachelor's, master's, and doctoral degrees in the field of Material and Manufacturing Engineering. Dr Fatchurrohman's research interest is in the field of product development. Other than that, he is also keen to work in the fields of material engineering and manufacturing processes.
E-mail: n.fatchurrohman@gmail.com

Nik Norika Natasha Nik Mat was a bachelor's degree student at the Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang. Her research interest was in the field of natural fibre polymer composites.

Mutiara Yetrina is a lecturer at the Faculty of Engineering, Universitas Putra Indonesia YPTK Padang. She has a bachelor's degree and master's degree in the field of Industrial Engineering. Her main research interest is in the field of product development.

Zuhaira Zulkfli earned her Bachelor's degree in Mechatronics Engineering from Universiti Malaysia Pahang, Malaysia. Currently, she enrols at the master degree student at the same institution. Her research interest is in the development of composites materials.

Jufriadif Na`am is a professor at the Universitas Putra Indonesia YPTK Padang. He has a Bachelor of Computer Master of Computer, and Doctor of Information Technology. He is registered as an IEEE member. Prof. Na'am's research interest is in the field of computer science including multi-criteria decision-making techniques.