Article
Journal of Technical Invention
December 2023 Vol.7 No.20 17-21

Analysis of the mechanical behavior of a heat diffuser for electrical cells made of natural fiber-reinforced composite materials

Estudio del comportamiento mecánico de un difusor de calor para celdas eléctricas construido con materiales compuestos reforzados con fibras naturales

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DOI: 10.35429/JOTI.2023.20.7.17.21 Received July 12, 2023; Accepted December 10, 2023

Abstract

The automotive industry is currently moving towards electrification of its vehicles to reduce CO_2 emissions. As a result, manufacturers are striving to offer electric vehicles that can provide the same benefits as internal combustion vehicles and, if necessary, improve them. The main component in the conformation of the electric cells adapted to the vehicles requires a distribution that allows them to be balanced on the chassis platform. In addition, a very important aspect to consider is the fact that the configuration of the cells must support proper ventilation so that they can dissipate the heat generated and optimize their operation. Therefore, in this paper it is proposed to provide an alternative that can support the ventilation of the cells, trying to take advantage of the momentum of the vehicle using a diffuser capable of driving the air into the cells and then out, which could generate greater stability to the temperatures generated in the cell and extend the life of the vehicle. A CAD model of the prototype will be designed based on modifications to the one currently used; this will be done to give rise to a degree of innovation in the development of production electric vehicles. On the other hand, it is considered to evaluate the functionality of such part simulating the basic conditions of resistance and deformation with the use of modeling software considering different types of materials: aluminum alloys; polymer matrix composites reinforced with fiberglass, carbon and reinforced with natural fibers, such as coconut fiber and jute.

Composites, Natural fiber, CAD Design, Strain distribution

Resumen

Actualmente, la industria automotriz se dirige a la electrificación de sus vehículos de producción con la finalidad de reducir las emisiones de CO_2 que estos modelos generan. En base a ello, las empresas armadoras buscan ofrecer vehículos eléctricos que sean capaces de brindar los mismos beneficios que ofrecen los vehículos de combustión y en su caso mejorarlos. El componente principal en la conformación de las celdas eléctricas adaptadas a los vehículos requiere una distribución que permitan estar balanceadas sobre la plataforma del chasis. Además, un aspecto muy importante a considerar es el hecho de que la configuración de las celdas debe dar soporte a una correcta ventilación para que puedan disipar el calor generado y se optimice su funcionamiento. Por lo que, en este proyecto se propone dar una alternativa que pueda brindar apoyo en la ventilación de las celdas, buscando aprovechar el impulso del vehículo usando un difusor capaz de conducir el aire hasta las celdas y luego salir, lo cual podría generar una mayor estabilidad a las temperaturas generadas en la celda y alargar la vida útil del vehículo. Se diseñarán un modelo CAD del prototipo basándose en modificaciones al que actualmente se ha empleado; esto con la finalidad de dar pie a un grado de innovación en el desarrollo de los vehículos eléctricos de producción. Por otra parte, se considera evaluar la funcionalidad de dicha pieza simulando condiciones básicas de resistencia y deformación con el uso del software de modelado (SolidWorks, Ansys) considerando diferentes tipos de materiales: aleaciones de aluminio; materiales compuestos de matriz polimérica reforzados con fibra de vidrio, carbono y reforzados con fibras naturales, como lo son la fibra de coco e yute.

Materiales compuestos, Fibras naturales, Diseño CAD, Distribución de esfuerzos

Citation: SÁNCHEZ-ROMERO, Ricardo Emmanuel, RODRÍGUEZ-DAHMLOW, Jesús Ernesto, MENDOZA-MIRANDA, Juan Manuel and SALAZAR-HERNÁNDEZ, Carmen. Analysis of the mechanical behavior of a heat diffuser for electrical cells made of natural fiber-reinforced composite materials. Journal of Technical Invention. 2023. 7-20: 17-21

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Journal of Technical Invention
December 2023 Vol.7 No.20 17-21

Introduction

The automotive industry is moving towards the electric car as the next step [1]. The structure of these vehicles is shown in Figure 1, where different components are defined with respect to an internal combustion engine vehicle. These vehicles are driven by one or more electric motors powered by the stored energy of an electric battery [2,3].

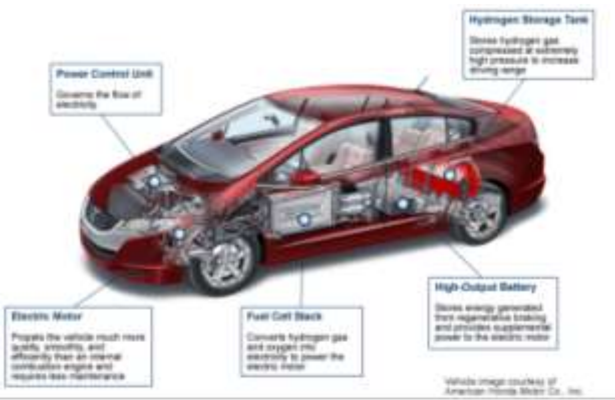


Figure 1 A diagram of the structure of a standard electric vehicle [2]

The most important component of an electric vehicle is the battery, since the vehicle's traction depends directly on it; therefore, there are many reasons why innovations are currently being sought to optimize and improve its performance. One aspect that is rarely considered is the possibility of using the vehicle's momentum to better dissipate the heat generated in this area of the vehicle.

The automotive industry is currently using composite materials as an alternative for manufacturing various components. These materials are formed by two or more different materials without any chemical reaction between them, i.e., a mixture is formed.

All composites have two components: the matrix, which is the main phase, and the reinforcing material, which is the material added to improve the properties of the matrix (Figure 2) [3,4]. Thus, composites are the product of two or more materials joined together to form a combination with properties that cannot be obtained from the original materials.

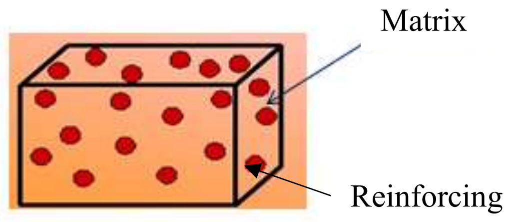


Figure 2 Structure of a composite

Composite materials can be classified according to the scheme shown in Figure 3, with fibers or particles as the main reinforcing agent [4,5].

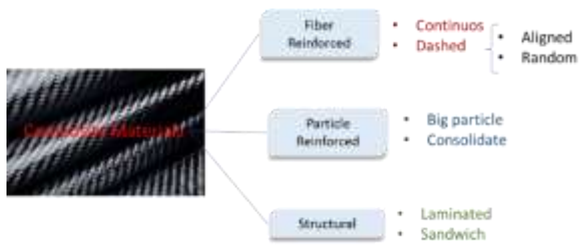


Figure 3 Classification of composites

The aim of this research is to analyze sustainable alternatives based on the modification of the diffuser design and its construction using natural fiber reinforced composite materials, which should be able to support the heat dissipation function of the battery and optimize the vehicle performance.

Methodology

Figure 4 shows a general diagram of the proposed methodology, which consists of the following steps:

Step 1. Development of the CAD model of the diffuser.

Step 2. Selection of mechanical properties of jute fiber reinforced composite materials. Properties such as mechanical strength, density, Young's modulus, elastic limit, percentage of elongation at break.

Step 3. Development of mechanical simulation using tetrahedral mesh.

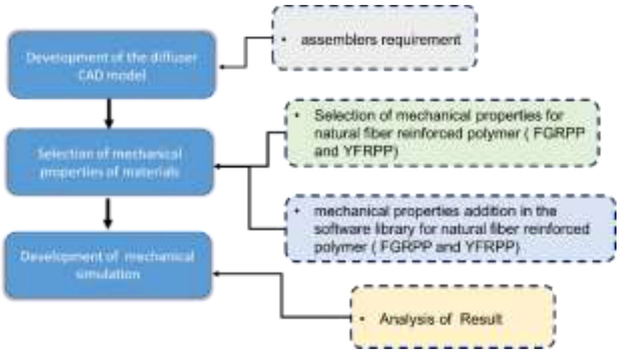


Figure 4 General Diagram of Methodology

Table 1 shows the proposed diffuser models; Figure 5 shows the meshing of the diffuser, consisting of a tetrahedral mesh with 4016 nodes and 7832 elements with a homogeneous compressive distributed load of 22.37 kN applied.

This load was applied according to equation 1, considering a mass of 3000 kg and an acceleration (equation 2) reached when the vehicle changes its speed from 100 km-h^{-1} to 300 km-h^{-1} (maximum speed reached by an electric vehicle) in a time of 7.67 s [6].

$$F = ma \tag{1}$$

$$a = \frac{v_f - v_i}{t_f - t_i} \tag{2}$$

Image	Model	Differentiation
	MD-1	Linear path model with oval inlet and rectangular outlet. Single outlet channel; 3 mm and 5 mm thickness.
	MD-2	Model with trajectory with a small ascending step. Oval shaped inlet and double outlet for air flow distribution in two; thickness of 3 mm and 5 mm.

Table 1 Proposed Diffuser Models

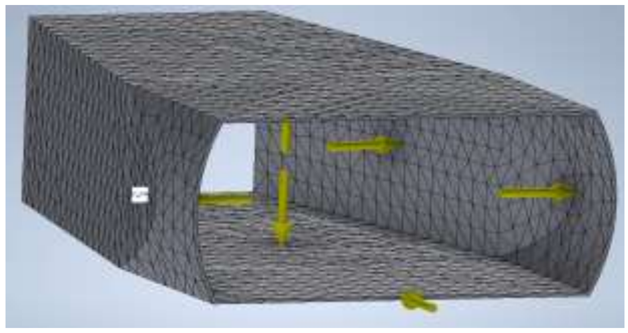


Figure 5 Meshing and load applied for simulation

Table 2 shows the mechanical properties of the materials; three materials Al-6061T4 (conventional automotive), glass fiber reinforced polypropylene matrix composite (GFRPP) and jute fiber reinforced polypropylene (YFRPP) were compared. Table 3 shows the constraints proposed for the simulation.

	Al-6061T4	GFRPP	YFRPP
Tensile Strength; σ_u (MPa)	207	77	50
Yield Strength; σ_y (MPa)	110	67	40
Elastic Module; E (GPa)	69	4.6	5.7
Density; ρ (g-cm^{-3})	2.70	1.13	1.11

Table 2 Mechanical properties required for simulation [ref]

	MD1	MD2
Fixture 1		
Fixture 2		

Table 3 Type of Constraints Used for Simulation

Results

Table 4 shows the von Mises stress distribution, σ_v (Equation 3), and the displacements generated in the 3 mm thick models; Table 5 summarizes the results obtained according to the diffuser thickness and the type of restraints.

ISSN 2523-6792

Less displacement is observed in aluminum because it is a material with higher stiffness than the composites. (E_{Al}= 69 GPa; E_{GFRPP}=4.6 GPa and E_{YFRPP}=5.7 GPa).

$$\sigma_v = \left[\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2} + 6\,(\tau_{12}^2 + \tau_{23}^2 + \tau_{13}^2)\right]^{\frac{1}{2}} \quad (3)$$

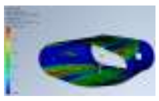
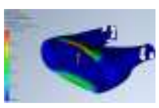
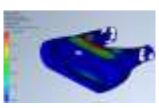
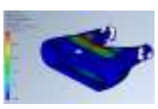
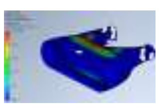
	Al-6061-T4	GFRPP	YFRPP
Stress Distribution			
MD1 Fixture 1			
MD2 Fixture 1			
MD1 Fixture 2			
MD2 Fixture 2			
Displacement distribution			
MD1 Fixture 1			
MD2 Fixture 1			
MD1 Fixture 2			
MD2 Fixture 2			

Table 4 Von Mises stress distribution and displacement by model and constraint type for the 3 mm thick diffuser

		σ_v maximum (MPa)	δ maximum (mm)	σ_v maximum (MPa)	δ maximum (mm)	Feasibility for build with YFRPP y/o GFRPP
		t= 3 mm		t= 5 mm		
Fixture 1 MD1	Al-6061T4/MD1	290	112.9	106	112.9	Not feasible
	GFRPP/MD1		1676		428.8	
	YFRPP/MD2		1352		346.1	
Fixture 1 MD2	Al-6061T4/MD2	581.3	77.93	240	21.18	
	GFRPP/MD2		1156		313.8	
	YFRPP/MD2		933		253.2	
Fixture 2 MD1	Al-6061T4/MD3	4.102	0.07864	1.98	0.02334	Feasible with t=3 and 5 mm
	GFRPP/MD3		1.144		0.3389	
	YFRPP/MD3		0.9231		0.2735	
Fixture 2 MD2	Al-6061T4/MD3	111	2.22	42.48	0.5687	Feasible with t= 5 mm
	GFRPP/MD3		33.31		8.54	
	YFRPP/MD3		26.88		6.87	

Table 3 Von Mises stresses

The configuration of the two models with fixture one results in σ_v higher than the ultimate strength of the material; therefore, it is not possible to use this configuration. By increasing the thickness, the stress decreases to 106 MPa; according to the material properties, only aluminum could be used (σ_v=110 MPa, for aluminum). However, it should be noted that the displacement generated is 112.9 mm; therefore, this configuration is not feasible.

The MD1 with fixture 2, gives a σ_v of 4 MPa with displacements of less than 2 mm, therefore its construction and adaptation to the electric vehicle is possible.

Conclusions

The choice of the fixing points in the diffuser structure allows to considerably reduce the stresses generated in the structure; a lower value of σ_v is obtained using fixing 2, where two reactions are placed to counteract the external loads on the diffuser wall. On the other hand, the wall thickness is another element that allows to reduce the generated stresses; having that the greater the thickness, the less σ_v will be generated On the other hand, the displacements must be analyzed to have the least impact on the structure, therefore, according to the simulation results, the most optimal configuration for the construction of the diffuser is given in MD1 with fixture 2 and thickness of 3 mm.

Acknowledgments

The authors would like to acknowledge CONACYT for the grant awarded to the student with CVU-1244894 on the program of Especialidad en Ingeniería para el Desarrollo de Sistemas de Manufactura at UPIIG-IPN.

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