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Simulation Study on Rice Husk Fibre - Recycled Polyethylene Composite for Electric Vehicle Floor Pan Insulation

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Abstract

The rapid growth of the electric vehicle (EV) industry has increased the demand for lightweight and sustainable materials for vehicle applications. Conventional floor pan insulation materials are mainly made from petroleum-based materials such as polyurethane and fibreglass. These materials can increase vehicle weight, reduce energy efficiency and create environmental problems during production and disposal. To overcome these issues, this study investigates the thermal performance of a sustainable composite made from Rice Husk Fibre (RHF) and Recycled Polyethylene (RPE). The proposed material uses agricultural and plastic waste, making it a more environmentally friendly alternative to conventional insulation materials. A floor pan model consisting of a 1.2 mm aluminium sheet and a 5.0 mm insulation layer was developed using ANSYS Workbench. The thermal performance of the RHF-RPE composite was evaluated under two conditions. The first condition simulated normal vehicle operation, where the floor pan was exposed to a temperature of 60°C for 1800 s. The second condition simulated a battery thermal runaway event, where the floor pan was exposed to 600°C for 600 s. The simulation results showed that the RHF-RPE composite achieved an average temperature of 47.013°C under steady-state conditions and reduced heat transfer by 66.65% compared to pure polyethylene. In the transient analysis, the composite required 89.21 s to reach 46.5°C, indicating a slower rate of heat transfer than pure polyethylene and EVA foam. During the battery thermal runaway simulation, the cabin-side surface temperature remained at 25.0°C throughout the 600 s analysis period. These findings indicate that the RHF-RPE composite has good potential as a sustainable insulation material for electric vehicle floor pan applications.

1. Introduction

The rapid growth of the electric vehicle (EV) industry has increased the demand for lightweight and sustainable materials for automotive applications. In EVs, the floor pan insulation is an important component because it reduces heat transfer from the battery system, electric drivetrain, road surface, and surrounding environment into the passenger cabin. Good insulation also improves passenger comfort by maintaining a stable cabin

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temperature and reducing road noise and vibration. Since EVs operate more quietly than conventional vehicles with internal combustion engines, noise from the road and tyres becomes more noticeable, making effective insulation increasingly important.

Conventional insulation materials, such as polyurethane foam and fibreglass, are widely used because they provide good thermal insulation and have relatively low weight. However, these materials are mainly produced from petroleum-based resources, which contribute to environmental pollution during manufacturing and disposal. In addition, heavier insulation materials increase vehicle weight, reducing battery efficiency and driving range. Fibreglass may also cause skin and respiratory irritation during handling, creating health and safety concerns for manufacturing workers. These limitations have encouraged the search for sustainable materials that provide comparable performance while reducing environmental impact.

At the same time, the increasing amount of plastic and agricultural waste has become a global environmental issue. Large quantities of plastic waste are generated each year, while rice production also produces significant amounts of rice husk as an agricultural by-product. Much of this waste is disposed of through landfilling or open burning, which contributes to environmental pollution. Recycling these waste materials into engineering products offers an opportunity to reduce waste while supporting sustainable manufacturing practices.

One promising approach is the development of biocomposites using Rice Husk Fibre (RHF) and Recycled Polyethylene (RPE). Rice husk fibre is lightweight, renewable, and has good thermal insulation properties, making it a suitable reinforcement material for composite applications. Recycled polyethylene provides good flexibility, moisture resistance, and chemical resistance, allowing it to act as the binding material for the composite. The combination of RHF and RPE has the potential to produce a lightweight and environmentally friendly insulation material for EV floor pan applications.

Although several studies have investigated natural fibre composites, limited research has focused on the thermal performance of RHF-RPE composites for electric vehicle floor pan insulation using numerical simulation. Information on their temperature distribution and heat transfer behaviour under normal operating conditions and battery thermal runaway events is still limited. Therefore, this study evaluates the thermal performance of an RHF-RPE composite using ANSYS Workbench and compares its performance with pure polyethylene and commercial EVA foam. The findings of this study may contribute to the development of sustainable insulation materials for future electric vehicle applications.

2. Literature Review

2.1 Vehicle Floor Pan Insulation Architecture

The function of the vehicle floor pan has changed with the development of electric vehicles (EVs). In conventional vehicles powered by internal combustion engines, floor pan insulation is mainly used to reduce heat from the exhaust system and noise from the engine and drivetrain. In contrast, the floor pan in an EV is located directly above the high-voltage battery pack and serves as a protective barrier between the battery and the passenger cabin [1]. Therefore, the insulation material must provide effective thermal protection while also reducing road noise and vibration. It should also be resistant to moisture, chemicals, and mechanical loading to ensure reliable performance under different operating conditions [2]. A typical vehicle floor pan consists of several layers, including the interior carpet, the structural floor panel, and the insulation layer [1].

In most electric vehicles, the battery pack is installed beneath the floor pan to improve weight distribution, lower the vehicle's centre of gravity, and increase passenger cabin space [3]. However, the close position of the battery to the passenger compartment increases the possibility of heat transfer during normal vehicle operation, fast charging, or battery thermal runaway events. For this reason, an effective insulation material is required to reduce heat transfer and improve passenger safety and comfort [4].

2.2 Thermal Insulation Mechanisms

Vehicle floor insulation controls heat transfer through three main mechanisms which are conduction, convection, and radiation. Conduction occurs when heat passes through solid materials such as the metal floor panel, insulation layer, and other structural components [5]. Insulation materials with low thermal conductivity, such as porous foams and natural fibre composites, reduce heat transfer by trapping air within their internal structure. Since air has a much lower thermal conductivity (approximately 0.02 W/m·K) than most solid materials, increasing the amount of trapped air helps improve the thermal insulation performance of the material [6].

Convection occurs when heat is transferred by the movement of air within small gaps between the floor layers or inside the porous structure of fibrous insulation materials. Proper sealing and bonding between the layers reduce air movement and help minimise heat transfer by convection [7].

Radiation is the transfer of heat through electromagnetic waves without direct contact between surfaces. In electric vehicles, radiant heat can be transferred from the battery pack to the vehicle floor through the air gap between them. To reduce this type of heat transfer, reflective materials such as thin aluminium foil can be added to the insulation system. These reflective layers help reduce the amount of radiant heat reaching the passenger cabin without significantly increasing the weight or thickness of the floor assembly [7].

2.3 Existing Insulation Materials

Several types of materials are commonly used for vehicle floor insulation, and each material offers different advantages and limitations.:

• Polymeric Foams (Polyurethane and Polyisocyanurate (PIR)): These materials are lightweight and provide good thermal insulation because they contain many closed air pockets that reduce heat transfer. They can also be easily formed into complex shapes to fit vehicle floor panels. However, they are produced from petroleum-based materials, have a relatively high environmental impact, may release volatile organic compounds during use, absorb moisture, and can present fire safety concerns [8].

• Ethylene-Vinyl Acetate (EVA) Foam: EVA foam is widely used in automotive floor insulation, carpet backings, and trunk liners because of its low thermal conductivity, good flexibility, and impact resistance. It is lightweight and can be easily shaped during manufacturing. However, like other synthetic polymers, EVA foam is produced from petroleum-based resources [9].

• Mass Barriers and Damping Mats (Butyl Rubber and Bitumen): These materials are mainly used to reduce noise and vibration by increasing the mass of the vehicle floor. Although they are effective for sound insulation, they provide limited thermal insulation and increase the overall weight of the vehicle [10].

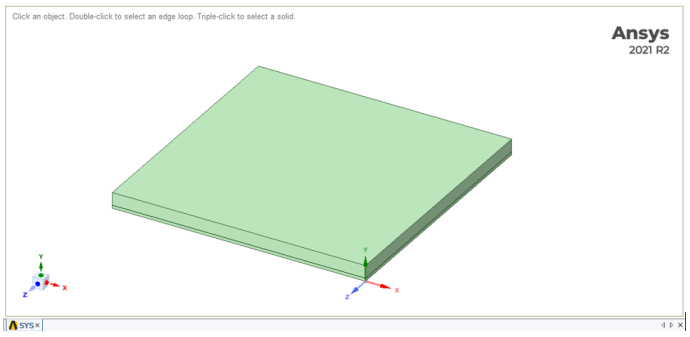
• Pure Polyethylene (PE): Pure polyethylene is a thermoplastic material with good chemical resistance and low moisture absorption. It is commonly used as a reference material when evaluating the performance of composite materials. However, pure PE has relatively low stiffness and may expand when exposed to high temperatures. These limitations can be improved by reinforcing the material with natural fibres [11].

3. Methodology

Numerical simulations were carried out using the finite element analysis (FEA) module in ANSYS Workbench 2021 R2. The thermal performance of the proposed Rice Husk Fibre-Recycled Polyethylene (RHF-RPE) composite was evaluated under both steady-state and transient conditions. Its performance was then compared with two commonly used automotive insulation materials, namely Ethylene-Vinyl Acetate (EVA) foam and Pure Polyethylene (PE).

3.1 Geometric Domain and Material Properties

The simulation model represents a section of a typical multi-layer vehicle floor pan assembly. Fig.1 shows the model dimension created in ansys SpaceClaim. The model has dimensions of 100 mm × 100 mm and consists of two layers. The bottom layer is a 1.2 mm thick aluminium sheet, while the top layer is a 5.0 mm thick insulation material, giving a total thickness of 6.2 mm.



(a)

Fig.1 *Geometry Model*

The aluminium sheet and insulation layer were assumed to be perfectly bonded, allowing heat to transfer continuously across the interface without thermal contact resistance. The material properties used in the simulation were obtained from published experimental studies and assigned to each material in ANSYS Workbench. The material properties used in this study are listed in Table 1:

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Table 1 *Properties of material used for thermal analysis [12].*

Materials	Mass Density (kg/m^3)	Spesific Heat Constant Pressure, C_p ($J \cdot kg^{-1} \cdot K^{-1}$)	Isotropic Thermal Conductivity ($W/m \cdot K$)
RHF-RPE Composite	715.74	1900	0.16
Ethylene-Vinyl Acetate (EVA) Foam	100	2300	0.035
Pure Polyethylene (PE)	950	1900	0.45

3.2 Simulation Environments and Boundary Conditions

Two thermal simulation scenarios were developed to evaluate the performance of the vehicle floor pan under normal operating conditions and a battery thermal runaway event.

The first scenario simulated normal vehicle operation by exposing the lower surface of the aluminium sheet to a constant temperature of 60°C for 1800 s. The upper surface of the insulation layer was subjected to a convection boundary condition representing the passenger cabin, with an ambient temperature of 25°C. A steady-state thermal analysis was first performed to establish the initial temperature distribution before the transient thermal analysis. Automatic time stepping was used in ANSYS Workbench with an initial time step of 5 s, a minimum time step of 1 s, and a maximum time step of 20 s.

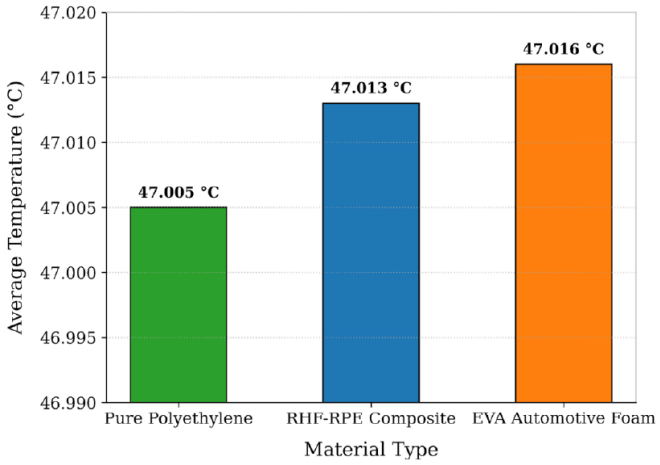
The second scenario simulated a battery thermal runaway event over a period of 600 s. The temperature applied to the lower surface of the aluminium sheet was defined using tabular data. The temperature increased from 25°C at 0 s to 600°C at 10 s, remained at 600°C until 300 s, and then gradually decreased to 400°C at 600 s. The upper surface of the insulation layer was subjected to a convection boundary condition with an ambient temperature of 25°C and a convection coefficient of h=1.0×10^7 $W/m^2 \cdot °C$. Automatic time stepping was also applied for the transient analysis, with an initial time step of 0.5 s and a minimum time step of 0.01 s to capture the rapid temperature changes during the early stage of heating.

4. Results and Discussion

4.1 Steady-State Thermal Analysis under Normal Driving Conditions

The steady-state thermal analysis evaluated the temperature distribution of the vehicle floor pan after prolonged exposure to a constant heat source. Under steady-state conditions, the applied boundary conditions remained constant, resulting in the same minimum and maximum temperatures for all material configurations. The minimum temperature was 25.0°C at the cabin side, while the maximum temperature was 60.0°C at the lower surface of the aluminium sheet. Therefore, the thermal performance of each insulation material was evaluated by comparing the volume average temperature and the total heat flux through the floor pan assembly.

Fig.2 shows a graph representing the data recorded based on the analysis that was carried out. The volume average temperatures of the three insulation materials were very similar under steady-state conditions. As stated in Fig.2, the proposed RHF-RPE composite recorded a volume average temperature of 47.013°C, which was slightly lower than that of commercial EVA foam (47.016°C). These results indicate that the RHF-RPE composite provides thermal performance comparable to EVA foam under the simulated operating conditions.



(a)

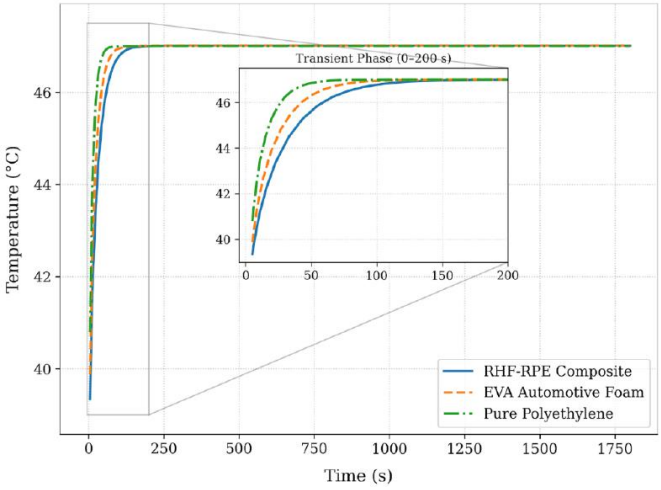
Fig. 2 *Average temperature distribution for Steady-state thermal analysis (a)*

4.2 Transient Characterisation under Road Heat Soak

The transient thermal analysis evaluated the temperature response of the floor pan over a period of 1800 s under normal operating conditions. Based on the analysis results that have been turned into a graph in Fig.3, Pure polyethylene showed the fastest increase in temperature, recording an initial temperature of 40.802°C at 5 s and reaching the reference temperature of 46.5°C after 39.89 s. EVA foam exhibited a slower temperature increase, requiring 59.46 s to reach 46.5°C. The RHF-RPE composite showed the slowest temperature increase, with an initial temperature of 39.890°C at 5 s and requiring 89.21 s to reach 46.5°C. These results indicate that the RHF-RPE composite delayed heat transfer more effectively than pure polyethylene and EVA foam under the simulated operating conditions.

The extended simulation period shows how each material responds during the early stage of heat exposure. At the start of the driving cycle (t = 5 s), a sharp increase in heat flux was observed across all materials due to the sudden change in temperature. Pure polyethylene recorded an initial heat flux of 10,650.0 W/m^2. The RHF-RPE composite reduced this initial peak to 6,736.8 W/m^2, while EVA foam recorded 4,125.0 W/m^2.

After this initial response, the heat flux decreased rapidly within the first 150 s as temperatures within the structure began to stabilise. The values then approached steady conditions for the remainder of the 1800 s simulation. The temperature at the cabin-side surface remained constant at 25.0°C for all materials throughout the analysis period, indicating that heat transfer to the cabin side was effectively prevented under the simulated normal driving conditions.



(a)

Fig. 3 *Temperature distribution for Transient thermal analysis (a)*

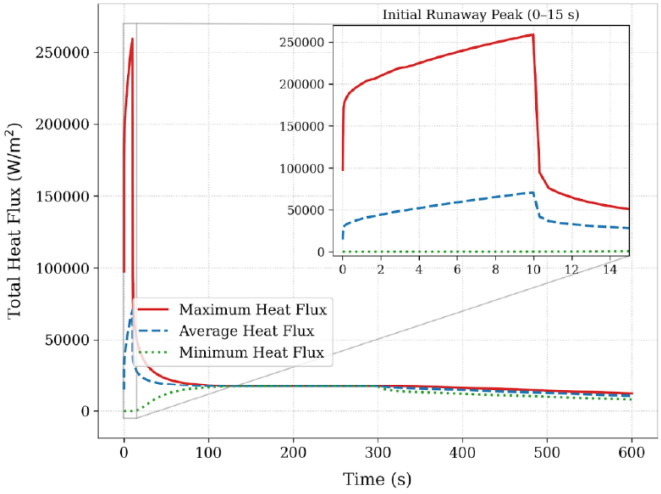
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4.3 Transient Thermal Analysis for Battery Thermal Runaway

During the simulated battery failure event, the lower surface of the floor pan was exposed to a time-dependent heat load representing an underbody fire. The temperature increased rapidly to 600°C within 10.31 s and remained at this level until 298 s. Heat then gradually passed through the RHF-RPE composite layer, resulting in a maximum volume average temperature of 386.65°C at 298 s. During the cooling phase, the average temperature decreased to 264.83°C at 600 s as the applied heat load reduced to 400°C. The minimum temperature in the model remained at 25.0°C throughout the simulation, indicating that the upper region of the structure was not affected by the high-temperature exposure.

The total heat flux results in Fig.4 showed a similar trend. A sharp increase was observed at the beginning of the event, reaching a maximum value of 259,220 W/m^2 at 9.975 s and an average value of 70,821 W/m^2 at the same time. After this initial increase, the transmitted heat flux decreased to 94,549 W/m^2 at 10.31 s. Between 100 s and 300 s, the heat flux values became more stable, averaging around 17,247 W/m^2 during the high-temperature period. During the cooling phase, the maximum heat flux gradually decreased to 12,019 W/m^2 at 600 s.

The temperature at the cabin-side surface remained constant at 25.0°C throughout the 600 s simulation period. This indicates that the RHF-RPE layer limited heat transfer to the upper surface under the conditions simulated in this study.



(a)

Fig. 4 *Total heat flux of RHF-RPE Composite for Transient thermal analysis during thermal runaway (a)*

5. Conclusions

This study achieved its objectives by evaluating the thermal performance of a Rice Husk Fibre-Recycled Polyethylene (RHF-RPE) composite for use as a vehicle floor pan insulation material.

For the first objective, material comparison showed that combining rice husk fibre with recycled polyethylene produces a lightweight composite with improved thermal insulation properties compared to pure polyethylene. This suggests that agricultural waste and recycled plastic can be used together to form an alternative insulation material.

For the second objective, finite element simulations under normal road heat conditions (60°C) showed that the RHF-RPE composite reduced total heat flux by 66.65% compared to pure polyethylene. It also showed a slower temperature increase, taking 89.21 s to reach 46.5°C, compared to both pure polyethylene and EVA foam.

For the third objective, under a simulated battery thermal failure condition (600°C), the composite limited heat transfer to the upper surface. The cabin-side surface temperature remained at 25.0°C throughout the 10-minute simulation period, indicating stable thermal insulation performance under extreme conditions.

In conclusion, the RHF-RPE composite shows potential as an alternative to conventional petroleum-based insulation materials in electric vehicle floor pan applications. The use of rice husk fibre and recycled polyethylene also supports waste reduction by utilising agricultural by-products and plastic waste.

Acknowledgement

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