Mitigating Energy Requirement in Transport System Via Material Selection

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Abstract. In view of sudden changes in climatic weather conditions, resulting in variation and dislocation of environment and biodiversity, there has been new initiatives in automotive industry to develop a lighter and sustainable materials to mitigate fossil fuel demand in transport system and improve the overall vehicular part maintenance. In almost all the developed part of the world, major car manufacturer have evolved new composite materials to replace original equipment body as government regulations become stricter in response to worsening environmental degradation. The concept of this paper is to report findings on new material formation using hand lay-up as manufacturing technique. In this paper, part of the novel approach in transport system is the possibility of payload reduction through the adaptation of new materials as external and internal parts of the system. Five materials were processed in this work with two specimens oriented at varying degree (30° and 60°) while the other three were without degree of orientation. The payload of these materials were estimated using all the conceptual parameters of a typical vehicle system and the findings from this research showed that 10%wt. of fibre at 30° orientation in the matrix, will possibly offer the lowest panel weight as presented in this paper. This study may be investigated further with a view to test the energy consumption of this new material via-a-viz other reinforced composite materials.

1. Introduction
Thermal insulation has remained a challenge globally considering huge resources required to maintain an optimum insulation thickness for effective energy conservation. In order to maintain an unbroken insulation properties, considerations are given to the optimum thickness of insulation and the properties of the external wall materials [1]. Energy demand in most transport system are increasing with new approach to contain the aftermath effect of excessive fossil fuel usage. Part of the reason responsible for increasing energy demand is population growth and the industrial revolution [2]. These two factors have made huge contribution to fossil fuel demand with increasing number of people demanding energy to power their vehicles [3]. The growth in modernization has evolved a global challenge that has brought untold hardship to most countries of the world. Climate change and the attendant effect is now real than ever imagined [4]. Water level are rising in some countries and there is drought in several other countries: all are aftermath of climate change. While efforts have been sustained at various level to reduce these effects, there seems to be little improvement in the climate stability as evidenced in the severity of the global warming and the resultant greenhouse effects.
Reducing energy consumption in vehicles is largely anchored on the weight or payload of the vehicle which is a function of the materials use in the build-up process [5]. The attempt in various published works on the efficient vehicles may be viewed from different dimensions depending on the approach energy was optimized. Modification of materials in terms of structural composition and manufacturing technology have been deployed in modern vehicles over the past years. All these aforementioned features in modern vehicles has indirectly constituted additional load and in the long run, create a challenge on how to maintain the performance while reducing the fossil fuel demand in these vehicles. The introduction of lightweight materials has improved vehicle performance in no small measures [6]. What is now important is the possibility of evolving further weight reduction in line with global best practices. These materials are quite necessary following their low density properties and thermal conductivity. There is still a lot of argument on the percent reduction in weight of these vehicles to attain desirable saving seal without compromising on the performance, the property, manufacturability, and cost requirements. There are also concerns on automotive structures of some of these vehicles as some reports had it that the existing set of advanced lightweight materials have not met the required modification while other suggested further development [7]. The existing developmental process for new materials for energy saving may require many years and several studies to complete. The new materials deploy for part formation are sometimes difficult to optimize their use in the context of various parameters surrounding vehicle performance such as weight, cost, crash behaviour, surface finish, etc. Some of the design process for vehicle formation relies solely on simulation and a follow-up accurate models to determine the sustainability and durability of lightweight materials. Part of the ongoing effort to reduce the complexity of large experimental matrices and iterative testing in the evolution of new materials for automotive vehicles is the introduction of some integrated computational materials engineering (ICME) approach. Vehicles and their associated movement was reported to account for about 28% of the total fossil fuel demand in the U.S. as at 2010. Further studies [8] confirmed that other sector sourced energy from different sources while transportation system rely solely on petroleum. Figure 1 shows the proportion of energy consumption by sectors as part of statistical data affirming that passengers and commercial vehicles (their aggregate density) account for total fossil energy, nearing 5.3Mbpd of petroleum product consumption due to weight imposition on vehicular movement. This aggregate load on transportation is a clear understanding on the quantitative relationship between weight and equivalent energy consumption. Therefore, efficient cars in term of minimal fuel consumption is better appreciated when the entire vehicular parts is properly reduced with the application of lightweight materials.

![Figure 1. Demand of fossil fuel energy by sectors](image-url)
The external reinforcing sheet of most vehicles are covered with aluminium sheet and in most cases served as the interface between indoor and outdoor environment. Virtually all vehicles are insulated against ambient temperature in line with outside environment conditions and inside thermal comfort. Thermal insulation is used as a sandwich between the internal aluminium sheet and the external materials so as to decrease energy consumption of fuel and the entire maintenance cost. The fossil fuel energy cost decreases while the insulation degrades in thickness over a length period of time. Thus, the fuel cost will be the lowest value at optimum thickness of the insulation. The implication of the approach is that there will be significant energy savings at early life of sandwiched insulation while more energy demand will begin to feature due to wear and degrading properties of insulation. Reports have indicated that some insulation products are naturally or human made and sometimes shows features in line with compositional variation effected from heat impact at ambient temperature. It is also of note that this thermal insulation materials can also display temperature dependent properties that rely on the nature of the material formation.

2. Theoretical method of experimental approach
The method adopted for this research work is highlighted below.

a. Composite formation were processed by hand-up technique at 0°, 30° and 60°.

b. The reinforcing fiber used for this work is glass fibre while the matrix is epoxy resin used as received. In order to create a unique representation for the materials used in this work, G was denoted as glass fibre while E was represented as epoxy resin.

c. The percent composition of fibre and resin were carefully denoted and represented based on the weight proportion of glass fibre and epoxy in the emerging composite, i.e. G10E, G20E, G30E shows proportion of glass fibre in the composite at 0° degree orientation. This is also applicable to G10E30 and G20E60 where the subscripts at E is the oriented angle of the fibre with respect to the resin.

d. The calculated insulated panel was assumed as a payload density of the typical vehicular movement taking into consideration all the equations (1)-(3).

\[
\text{Density} \rho \left( \frac{g}{cm^3} \right) = \frac{M_e - M_d}{V_d} \tag{1}
\]

\[
M(\%) = \frac{(m_f - m_i)}{m_i} \times 100 \tag{2}
\]

\[
TS(\%) = \frac{h_f - h_i}{h_i} \times 100 \tag{3}
\]

e. In this step, actual insulation thickness for varying degree was assumed, thereby leading to the application of the equation (4)-(5)

\[
\text{Weight (Kg)} = L \times W \times T \times \text{density} \left( \frac{g}{cm^3} \right) \tag{4}
\]

\[
\text{Panelweight} (Kg/m^2) = \frac{\text{Weight} (Kg)}{LW} \tag{5}
\]

3. Analysis of results
The variation in panel weight, using all the existing metallic sheets as the cover wall of vehicular parts were analysed. The insulated panel considered in this work refers to the weight of the aluminium and other materials as the cover sheets together with the weight of the insulation and the external cover sheet. In this case, the internal and the external sheets may be the metallic materials or the five materials considered. This concept enables the researchers to predict the payload weight and the
impact it has on energy demand in transport system. Part of the assumption adopted is a typical insulated panel with planar dimensions of 1000mm by 1000mm, and it is also assumed that the varying insulation thickness is ranged between 50mm to 100mm which is still the existing insulation thickness used to mitigate heat infiltration. It is of interest to consider the AISI density for aluminium and iron sheet, as the density of all the composite materials were computed as indicated in equation (1)-(4) leading to computation of Table 1.

Figure 2 shows the variation and the proportion of weight difference in aluminium material and the iron sheet. The large weight shown by the iron sheet may not be unconnected with their high density as compared with the aluminium. The implication of the variation on vehicle part can only be felt on the energy consumption for this particular cars with this sheet metal. Aluminium sheet is widely acknowledged as light material but its thermal conductivity is high likewise iron sheet. This can also attract heat infiltration resulting in more fossil fuel consumption. This has been a long setback for users of aluminium sheet. This study also went further to consider the five new materials processed for this application as shown in figure 3 and elaborated in Table 1 due to insignificant value difference among the five composite materials. It can be noticed in figure 3 that as the insulation thickness increases so also the panel weight increases and this is predominantly felt in all the composite materials, irrespective of fibre loading and orientation. The same scenario was portrayed in the metallic sheets as shown in figure 3. Further observation shows that G10E30 gives the lowest panel weight indicating best insulated panel as a function of the oriented fibre with respect to the resin. At 60° orientation, it can be seen that G20E60 panel weight is lower than G20E despite the same composition of 20% of glass fibre in each cases. The same deduction is demonstrated in the case of G10E30 which offers 2.2% panel weight decline as against G10E. Further experimental works may be needed to ascertain the impact of orientation of weight reduction in order to corroborate these findings. Some works have attributed this reduction to appropriate alignment of the oriented fiber with the respect to base matrix.

![Panel weight of aluminium and iron sheet.](image-url)
Table 1. Panel weight density of metallic materials and five composite materials with varying insulation thickness

| Insulation thickness (mm) | Panel weight (Kg/m²) for Aℓ | Panel weight (Kg/m²) for Fe | Panel weight (Kg/m²) for G₁₀E | Panel weight (Kg/m²) for G₂₀E | Panel weight (Kg/m²) for G₃₀E | Panel weight (Kg/m²) for G₁₀E₃₀ | Panel weight (Kg/m²) for G₂₀E₆₀ |
|--------------------------|-------------------------------|-----------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| 50                       | 12.3000                       | 32.9800                     | 5.3552                        | 5.4288                        | 5.4304                        | 5.2380                        | 5.4116                        |
| 75                       | 13.0500                       | 33.7300                     | 6.1052                        | 6.1788                        | 6.1804                        | 5.9880                        | 6.1616                        |
| 100                      | 13.8000                       | 34.4800                     | 6.8552                        | 6.9288                        | 6.9304                        | 6.7380                        | 6.9116                        |

4. Conclusions

Attempt to reduce vehicle parts has been demonstrated in many literature with improvement in the complexity of the manufacturing process, resulting in reduction in petroleum consumption by increasing efficiency in existing vehicles and improving the market competitiveness in electric cars. Despite some of these giant strides in weight reduction as evidenced in the evolution of advanced high-strength steels, aluminium alloys, magnesium alloys, fibre reinforced composites, and advanced polymers materials, there seems to be more energy consumption in fossil fuel supported vehicles. This may be due to the large varieties of technical challenges that require continued research and development. Part of the limitation has always been in the area of lightweight designs which employs the use of multi-material structures. This additional materials may further widen the gap associated with joining, corrosion protection, and design. Some researchers have explored the concept of supplementing classical materials as contained in R&D techniques with computational materials science to bridge this gap. This approach as suggested in other works may require further improvement due to variation in the results. Part of the progress highlighted in this paper is the weight reduction offered by the orientation approach which may require further research and improvement.
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