Investigation of CFRP-Balsa Wood Sandwich Composite as an Alternative for Commercial Floor Pan Material

Ezhil Ruban L[1], Anto Jeyaraj D[2], Akash B[3], Desmond Nirmalraj J[4], Akash Darin V[5]

[1]*Assistant Professor, Student, Department of Mechanical Engineering, Loyola-ICAM College of Engineering and Technology,*
[2,3,4,5] *Student , Department of Mechanical Engineering, Loyola-ICAM College of Engineering and Technology, Chennai, Tamil Nadu, India*

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Abstract - *The transformations in the automotive world are generally based on energy efficiency irrespective of whether it is a fuel based or a hybrid or an electric vehicle. Each and every part or component of a vehicle contributes to some extent of the vehicle's weight. In that case, the floor pan which forms the floor setup in passenger cabin and the base for seat contributes to a considerable amount of weight to the vehicle body. This paper represents the investigation of Balsa wood sheet sandwiched between carbon fibre reinforced polymer as an alternate material for the floor pans in automobiles. The core material - the balsa wood has high strength to weight ratio. Hence a composite with balsa wood as core is designed and analyzed whether it could be an alternative for steel and aluminium floor pans.*

Key Words: Floor Pan, Balsa wood sheet, Carbon Fibre Reinforced Polymer (CFRP).

1. INTRODUCTION

The composites are materials that are developed to obtain combined properties for an application. The composites generally involve two or more materials with different physical and chemical properties that when combined exhibit the combined properties of both the materials. This investigation is aimed towards using a composite material as an alternative material for the steel and aluminium floor pans in automobiles. This polymer matrix composite has its core material as the balsa wood (Ochroma Pyramidale) which is sandwiched between epoxy resin matrix that are reinforced with carbon fibres. The balsa wood is generally known for its strength to weight ratio. Apart from that, it has a wider range of flexibility towards manufacturing and also it absorbs shocks and vibrations. The carbon fibre in the form of woven fabric has high stiffness, high tensile strength and lesser weight are used in the aerospace, automotive sectors and Marine applications. The epoxy resins are the most widely used polymer for their high strength and excellent adhesion properties. Hence combining the above materials, would provide an end product which is a composite with the desired properties for the application which is the floor pan of automobiles. The floor pan is designed and analyzed with properties of steel and aluminium using Ansys and with properties of proposed composite material using Ansys Composite PrepPost.

2. LITERATURE REVIEW

2.1 Preparation and Characterization of the Carbon Fiber reinforced epoxy resin Composite

Authors: Prashanth Banakar, H.K. Shivananda

The analysis tensile and flexural behavior of carbon fiber reinforced polymer laminates through experimental investigation lead to the following conclusions. In case of 90-degree orientation, the external tensile load is equally distributed on all the fibers and transmitted along the axis of fibers. The tensile and flexural strengths are superior in case of 90-degree fiber orientation. Specimen sustain greater load at 90-degree orientation specimens than in other orientations. Extension and deflection are minimum in case of 90-degree orientation and maximum in case of 30-degree orientations.

2.2 A Review on usage of carbon fiber reinforced plastics in automobiles

Authors: Masilamani, N.V. Dhandapani, K. Vignesh Kumar, K. Tamil Mani

Carbon composites are unparallel in their ability to reduction of mass, facilitate sleek, aerodynamic shape, eliminate corrosion and denting, improve sound damping and vibration. It is found that the Carbon Fiber Reinforced Composites (CFRP) has reduced cost and weight compared to conventional steel and aluminium. It has about 60% weight reduction in comparison with steel. Similarly, the composite has 40% reduction in weight in comparison with aluminium.

2.3 Mechanical Characterization of glass fibre strengthened balsa-depron composite

Authors: Nallusamy Tamilselvan, S. Varsha, D.S. Seema, B. Indhumathy

The strengthening of balsa wood is done by adding glass fiber and depron sheet as a strengthening agent. The addition of glass fiber increases the mechanical as well as thermal withstanding capability of the plain balsa wood. The tensile and flexural strength of this composite was tested and found to be better comparatively. The glass fiber strengthened composites are more suitable for light weight unmanned aerial vehicle construction.

2.4 Characteristics of Balsa Wood Mechanical properties required for continuum damage mechanics analysis

Authors: G Newaz, M Mayeed, A Rasul.

Balsa wood is widely used as a core material in sandwich composites, since it is much stiffer in the grain direction than in the in-plane direction and that gives this material significant advantage in resisting out-of-plane deformation and transverse impact loads, compared to other core with similar density. At the higher load level, the experimental value suddenly went down due to the global buckling of the wood sample and the strength again increased due to the tension in membrane. In case of experiment, the wood sample suddenly crashed and the load dropped down to zero.

3. RESEARCH GAP

The balsa wood itself has good mechanical properties such as good strength to weight ratio, but the balsa wood alone is not good enough to be used in automobile components considering the properties of material comparatively and also the safety of passengers. Hence the core balsa has to be strengthened with fibers to improve their properties. Glass fiber strengthened balsa composites show increased mechanical as well as thermal withstanding capability but are more suitable only for light weight unmanned aerial vehicle construction.

The carbon fiber reinforced epoxy resin composites, on analysis have shown good mechanical properties, especially the carbon fibers that are oriented at perpendicular to the loading direction are superior in tensile and flexural strength and the external tensile load is distributed equally along the axis of the fibers, thus sustaining greater loads. The CFRP's proved to be lesser in weight and compared to conventional steel and aluminium.

Hence, the objective of this investigation is to reduce the weight in the floor pans of automobiles by using an alternate material apart from conventional steel and aluminium. The balsa wood has found to be a light weight material with high strength to weight ratio but lesser strength compared to Steel & Aluminium. So, the properties can be enhanced by sandwiching the wood between carbon fibers reinforced polymer, such that it could replace aluminium and steel floor pans on the basis of weight.

4. DESIGN OF FLOOR PAN

The floor pan is designed using Solid Works in both solid modelling technique considering the **thickness as 7mm** and also using surface modelling technique. The basic difference between the solid and surface modelling technique is that, the solid models portray the component being designed in 3d form itself i.e., it involves the thickness of the component too whereas in ACP, a surface model of the floor pan is required because ACP requires shell elements to carry on the analysis. The analysis of steel and aluminium floor pan can be solved directly using ANSYS Workbench. Whereas to analyze the floor pan made of composite, it cannot be done as such and hence requires a special analyzing interface known as Ansys Composite PrepPost (ACP).

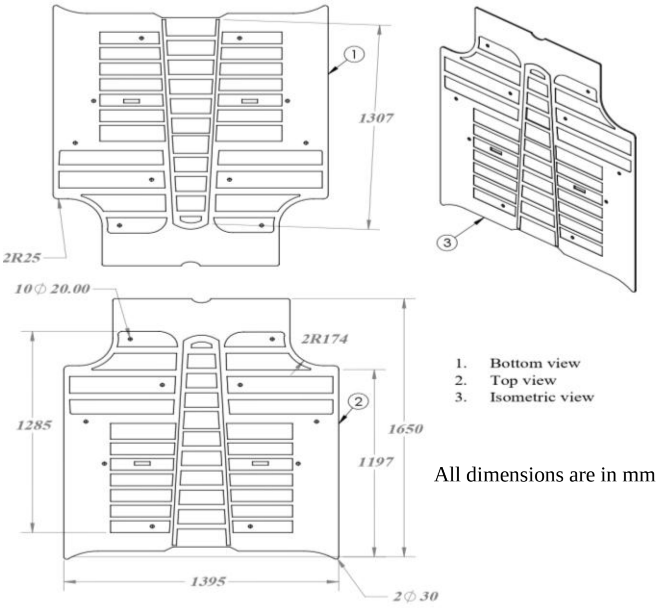

Fig -1: Two-Dimensional Representation of Floor Pan

5. ANALYSIS OF FLOOR PAN

The designed floor pan is imported to the Ansys software and the material is defined respectively. The geometry of parts such as stiffness behaviour and coordinate systems are set to flexible and global coordinate system respectively. The floor-pan may undergo extreme conditions during its life time and hence the environment temperature is set to 45° Celsius and twice the load of the passengers was provided. The analysis type is defined as transient. The floor pan is generally fixed to the chassis. Hence the outer boundary, the Centre region along with the other floor pan mounting regions are set fixed.

Since transient analysis is conducted, the time duration of the analysis is set to 6 seconds and the load varies at each second considering the weight and movement of the passenger as well as the road condition. The maximum loading is defined to occur at the 4th second assuming that the vehicle passes through a bump. The loading conditions along the negative y-axis are as follows.

Table -1: Loading Conditions

Time (Seconds)	Force on left side of floor pan (N)	Force on right side of floor pan(N)
0	1360	1480
1	1720	1840
2	1720	1870
3	2240	2410
4	2780	2900
5	1960	2080
6	1720	1840

5.1 Analysis of floor pan with the properties of Steel

The floor pan model designed using Solid Works is imported to Ansys and the material of the floor pan is determined as structural steel. The properties of structural steel are taken into consideration and the Transient Analysis is carried out.

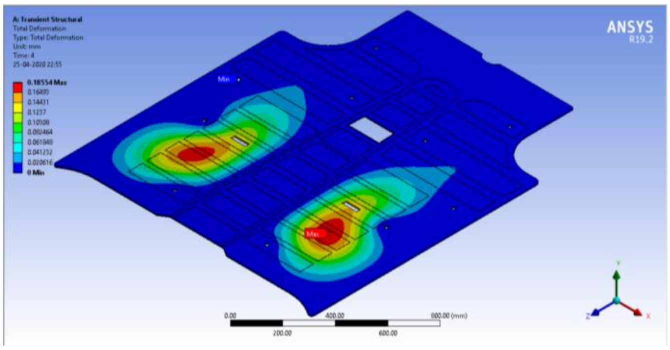

Fig -2: Total Deformation (Structural Steel)

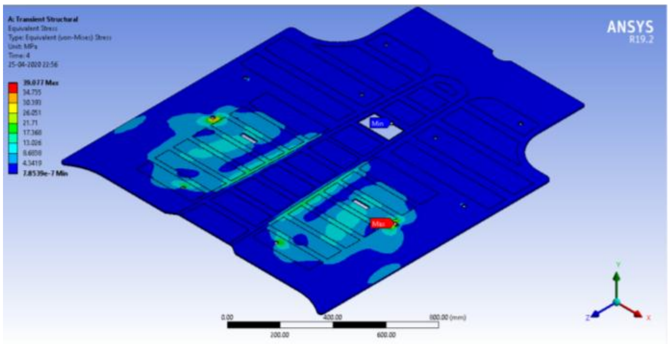

Fig -3: Equivalent Stress (Structural Steel)

From the analysis, the following results are obtained.

Table -2: Outputs (Structural Steel)

Mass (kg)	111.32
Total Deformation (mm)	0.18544(Max)
Equivalent Stress (MPa)	39.077(Max)
Factor of Safety	4.5086

The strength to weight ratio is calculated using the load applied. The mass of the floor pan made of structural steel and the deflection (in this case, deformation along negative y axis) is obtained from analysis. The total load at 4th second is considered for calculation since it is the maximum.

$$\text{Strength to Weight Ratio}=\frac{\text{Ultimate Strength(MPa)}}{(\text{Mass} * 9.81)\ (\text{N})}$$

Strength to Weight Ratio of structural steel = 0.4213 mm^{-2}

5.2 Analysis of floor pan with the properties of Aluminium

The floor pan model designed using Solid Works is imported to Ansys and the material of the floor pan is determined as Aluminium. The properties of Aluminium are taken into consideration and the Transient Analysis is carried out.

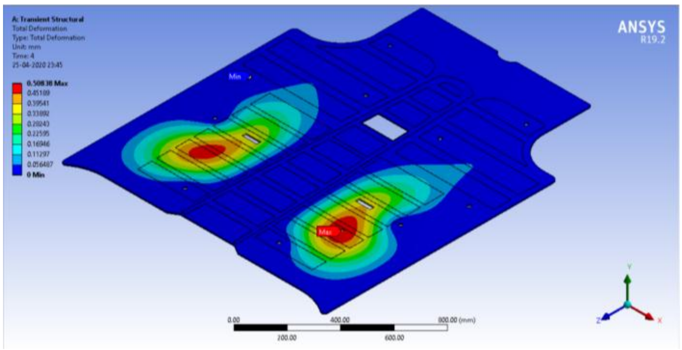

Fig -4: Total Deformation (Aluminium)

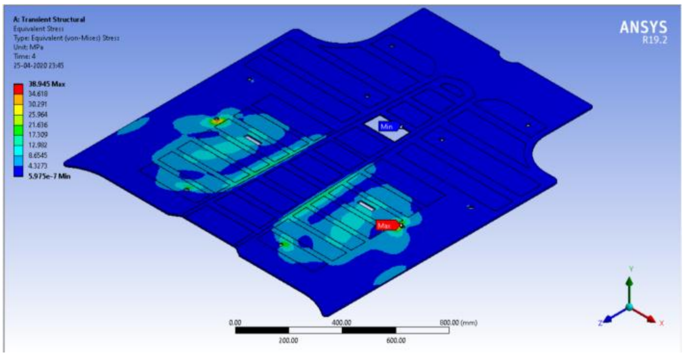

Fig -5: Equivalent Stress (Aluminium)

From the analysis, the following results are obtained.

Table -3: Outputs (Aluminium)

Mass (kg)	39.28
Total Deformation (mm)	0.50838(Max)
Equivalent Stress (MPa)	38.945(Max)
Factor of Safety	4.8124

Strength to Weight Ratio of Aluminium = 0.8045 mm^{-2}

5.3 Analysis of floor pan with the properties of Balsa Wood Composite at (0,45) Degrees Orientation

The floor pan designed using surface modelling technique is imported to the Ansys Composite PrepPost interface. The materials used in the composite are defined. The core material is the balsa wood. The binder along with the carbon fibre is defined as Epoxy carbon woven (230 GPa) PrePreg. All the Carbon fibre orientations are defined with reference to the loading plane. The carbon fibre orientations are set to(0,45) degrees such that 2 layers are oriented as per the given Orientation code: **[0/45/Balsa Wood]$_S$**. The thickness of each layer is defined as 1.25 mm such that the 4 plies make up 5 mm. The thickness of Balsa Wood is 2mm. On a whole, the thickness of the composite is 7mm.The properties of the materials are fed individually and the analysis is carried out.

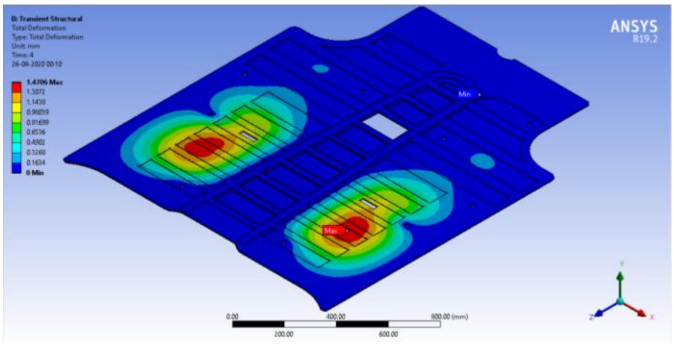

Fig-6: Total Deformation (Composite-(0,45) Degrees)

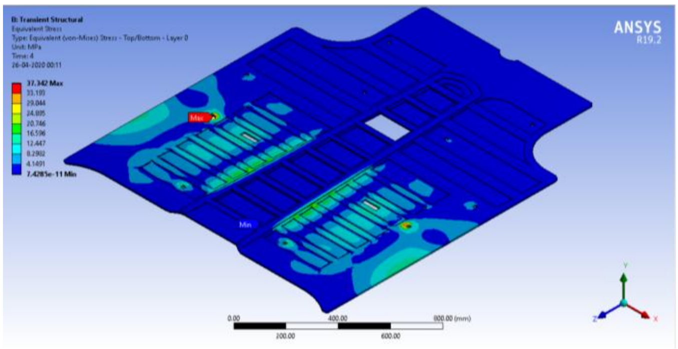

Fig-7: Equivalent Stress (Composite-(0,45) Degrees)

From the analysis, the following results are obtained.

Table -4: Outputs (Composite-(0,45) Degrees)

Mass (kg)	3.1065
Total Deformation (mm)	1.4706(Max)
Equivalent Stress (MPa)	37.342(Max)
Factor of Safety	7.2987

Strength to Weight Ratio of Balsa Wood Composite at (0,45) Degrees Orientation= 2.7892 mm^{-2}

5.4 Analysis of floor pan with the properties of Balsa Wood Composite at (45,60) Degrees Orientation

The carbon fibre orientations are set to (45,60) degrees such that 2 layers are oriented as per the given Orientation code: **[45/60/Balsa Wood]$_S$.**

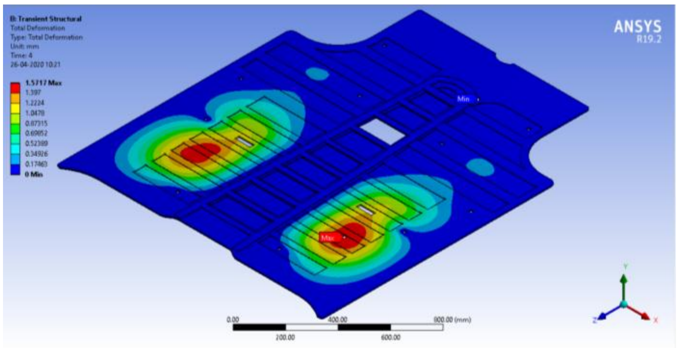

Fig-8: Total Deformation (Composite-(45,60) Degrees)

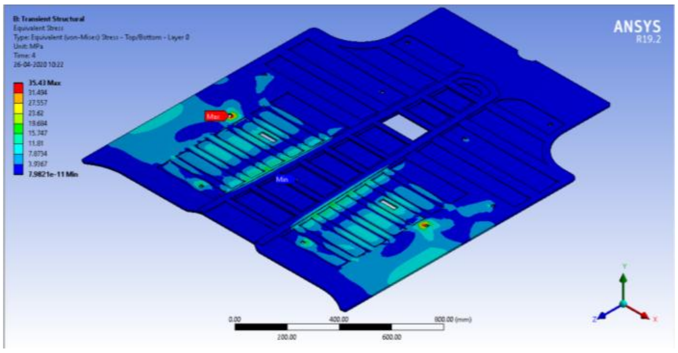

Fig-9: Equivalent Stress (Composite-(45,60) Degrees)

From the analysis, the following results are obtained.

Table -5: Outputs (Composite-(45,60) Degrees)

Mass (kg)	3.1065
Total Deformation (mm)	1.5717(Max)
Equivalent Stress (MPa)	35.243(Max)
Factor of Safety	1.3637

Strength to Weight Ratio of Balsa Wood Composite at (45,60) Degrees Orientation= 2.1329 mm^{-2}

5.5 Analysis of floor pan with the properties of Balsa Wood Composite at (60,90) Degrees Orientation

The carbon fibre orientations are set to (60,90) degrees such that 2 layers are oriented as per the given Orientation code: **[60/90/Balsa Wood]$_S$.**

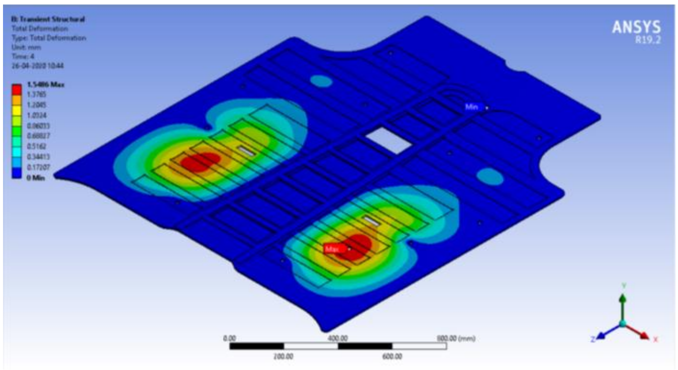

Fig-10: Total Deformation (Composite-(60,90) Degrees)

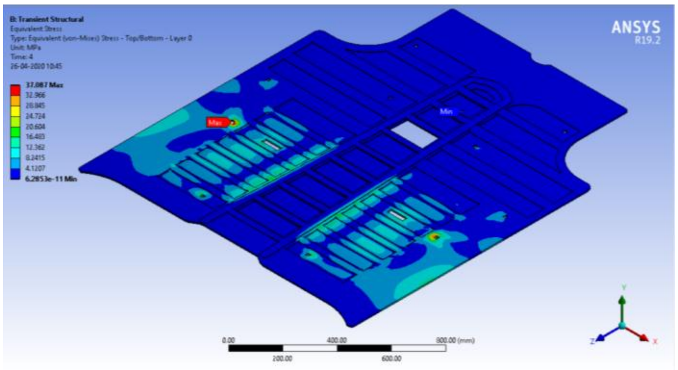

Fig-11: Equivalent Stress (Composite-(60,90) Degrees)

From the analysis, the following results are obtained.

Table -6: Outputs (Composite-(60,90) Degrees)

Mass (kg)	3.1065
Total Deformation (mm)	1.5486(Max)
Equivalent Stress (MPa)	37.087(Max)
Factor of Safety	6.3273

Strength to Weight Ratio of Balsa Wood Composite at (60,90) Degrees Orientation= 2.7892 mm^{-2}

6. RESULT INTERPRETATION

From the results of analysis, the following interpretations are made with the aid of graphs and charts. The equivalent stress is observed in a path along the width of the floor pan and the total deformation along the length of the floor pan based upon its maximum values. Also, the parameters such as the strength to weight ratio, safety factor and mass of the floor pan for different materials are compared using the bar graphs.

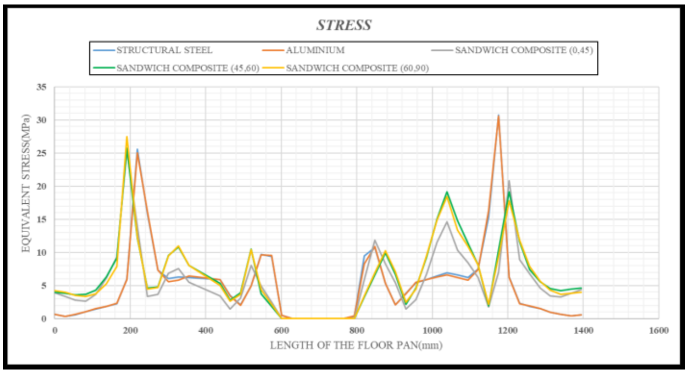

Fig-12: Comparison of Equivalent Stress

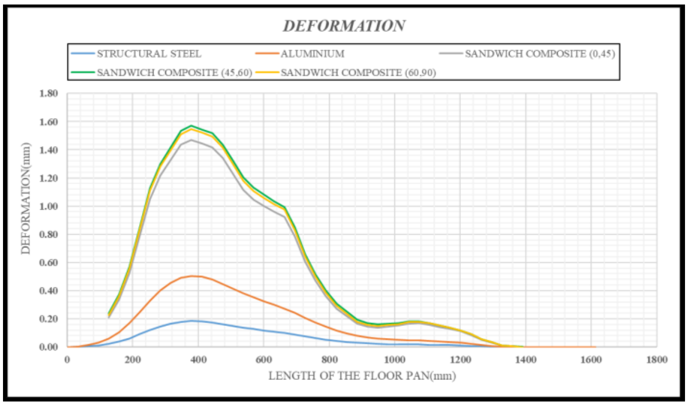

Fig-13: Comparison of Total Deformation

From the above line charts, we can see that the equivalent stress of structural steel and aluminium as well as the composite with 3 different orientations of carbon fibre are more or less in the same trend. But the deformation experienced by the structural steel and aluminium is lesser compared to all the 3 orientations of composite.

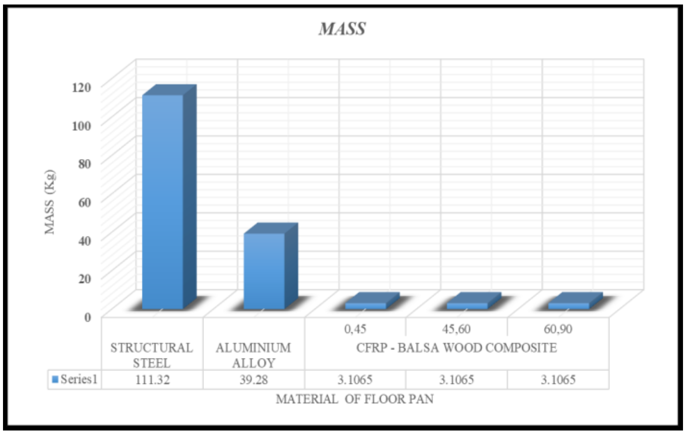

Fig-14: Comparison of Mass

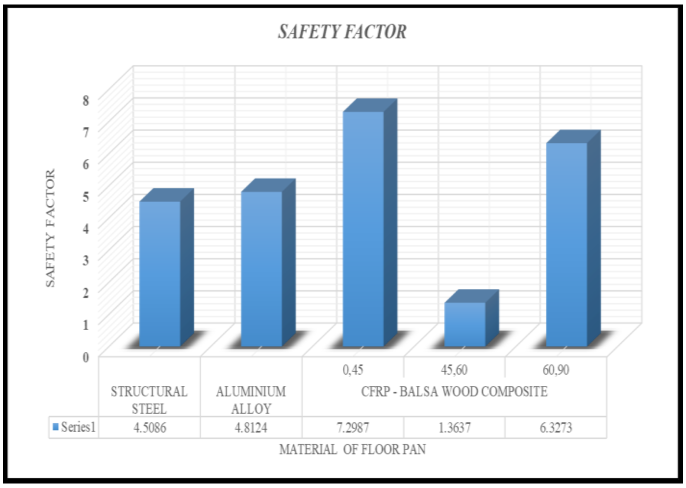

Fig-15: Comparison of Safety Factor

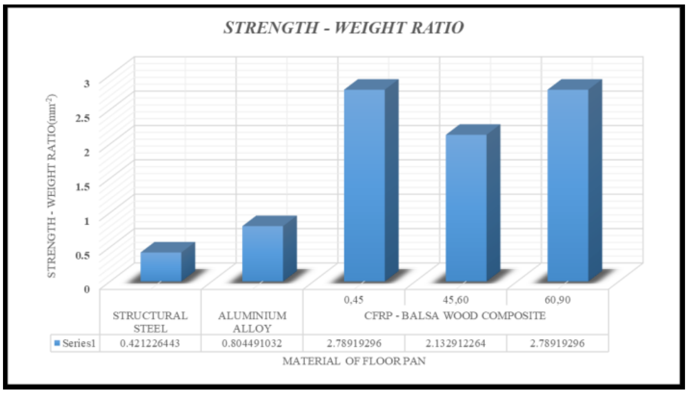

Fig-16: Comparison of Strength-Weight Ratio

From the bar graphs, it is evident that the mass of the floor pan made of composites is far more lesser than the structural steel and aluminium. The strength to weight ratio and safety factor of composites are also greater compared to the steel and aluminium, especially the composite with carbon fibre orientations at (0,45) degrees has the highest safety factor and strength to weight ratio.

7. CONCLUSIONS

The automobile floor pan made by sandwich carbon fibre reinforced balsa wood composite (of three different orientations), steel and aluminium are analysed using Ansys workbench and the results are compared, based on the following parameters such as mass, total deformation, equivalent stress, safety factor and strength to weight ratio. From the investigation, the following conclusions are made:

- It is evident that the sandwich composites (0,45 & 60,90 orientations) have out-performed aluminium and steel in the parameters such as safety factor, strength to weight ratio and has lesser weight comparatively.
- Steel and aluminium deformed lesser than all three sandwich composites, for the given loading and boundary conditions.
- The composite with the fibre orientation 0,45 has the best safety factor and strength to weight ratio, and hence it can be used as an alternative material for floor pan in a commercial or passenger vehicles.

There are future scopes for improvements since the sandwich composite deformed more than steel and aluminium. Hence the rigidity of the sandwich/stacked composite can be improved by using a suitable core material or strengthening the core with S-glass fibers.

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BIOGRAPHIES

Ezhil Ruban L,
Assistant Professor,
Department of Mechanical Engineering,
Loyola-ICAM College of Engineering and Technology

Anto Jeyaraj D,
Student,
Department of Mechanical Engineering,
Loyola-ICAM College of Engineering and Technology

Akash B,
Student,
Department of Mechanical Engineering,
Loyola-ICAM College of Engineering and Technology

Desmond Nirmalraj J,
Student,
Department of Mechanical Engineering,
Loyola-ICAM College of Engineering and Technology

Akash Darin V,
Student,
Department of Mechanical Engineering,
Loyola-ICAM College of Engineering and Technology