Journal of Electronics, Computer Networking and Applied Mathematics
ISSN: 2799-1156
Vol: 04, No. 05, Aug-Sept 2024
http://journal.hmjournals.com/index.php/JECNAM
DOI: https://doi.org/10.55529/jecnam.45.1.15

Design and Analysis of Composite Body Panels Using FEA and Mathematical Simulation

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Received: 30 March 2024 **Accepted:** 17 June 2024 **Published:** 03 August 2024

Abstract: This paper focuses on the design, analysis, and fabrication of the composite body panel structure used to enclose the BAJA vehicle's roll cage structure. Traditionally, this composite structure was created to replace expensive aluminium panels while also replacing acrylic and polycarbonate panels, which are weaker and can be just as expensive as composite panels. Composite panels can be made from fibreglass, carbon fibre, wood-plastic composite, etc. In this study, we shall begin with the material selection followed by the design calculations, software-based analysis, and practical applications of the composite panels along with the manufacturing methodology.

Keywords: Composite Materials, Tsai Wu Analysis, Sae Baja, Glass Fibre Composites, Lay-Up Process, Ansys.

1. INTRODUCTION

Composite materials are combination of two or more materials which when mixed will give certain properties that are not exclusively imparted by any of the material alone. Usually, this composition occurs on a macroscopic level wherein a reinforcement material is embedded in a matrix. The matrix is responsible for holding the shape of the structure and the reinforcement will improve the mechanical properties of the matrix.
Composite materials are increasingly being recognized as potent alternatives to conventional materials across various sectors, attributed to their unique amalgamation of properties. They offer an unparalleled combination of strength and lightness, which is not achievable with metals, ceramics, or polymers when utilized independently. For instance, in the aerospace sector, composites such as Carbon Fiber Reinforced Polymers (CFRP) are superseding metals owing to their superior strength-to-weight ratio and resistance to corrosion. In the realm of construction, composites like fiberglass are being employed as an alternative to steel for reinforcing concrete, primarily due to their immunity to rust and lighter weight. Similarly, in

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the automotive industry, the adoption of composites is on the rise to reduce vehicle weight, thereby enhancing fuel efficiency without compromising on safety. The versatility and superior performance characteristics of composites render them an attractive alternative for various applications. However, it is imperative to consider factors such as cost, manufacturability, and recyclability when opting for composites as alternatives. [1]

1.1 History

The evolution of composite materials has a rich and varied history, tracing its origins back to 1500 B.C. when early civilizations such as the Egyptians and Mesopotamians utilized a composite of mud and straw to construct robust structures. This primitive form of composite technology was also employed in the creation of pottery and boats. A significant advancement in composite technology occurred in 1200 A.D. with the Mongols' invention of the composite bow. Comprising wood, bone, and animal glue, these bows were formidable weapons that held sway until the discovery of gunpowder. The advent of the modern era of composites was marked by the development of synthetic plastics in the early 20th century. These plastics, which included vinyl, polystyrene, phenolic, and polyester, surpassed the performance of their natural resin counterparts. However, their lack of inherent structural strength necessitated the use of reinforcement. This led to the introduction of the first glass fiber, known as fiberglass, by Owens Corning in 1935. The combination of fiberglass with a plastic polymer resulted in a structure that was both incredibly strong and lightweight, heralding the birth of the Fiber Reinforced Polymers (FRP) industry as we know it today.

1.2 Motivation

The objective of fabricating composite body panels is to supersede the existing plastic-based panels, which exhibit characteristics such as brittleness, inadequate strength, limited machinability, and reduced capacity for flexibility and form creation. Additionally, it aims to replace metal-based panels (predominantly aluminum) that are heavier, more expensive, and require specialized equipment for forming specific shapes. The utilization of composite reinforcement and matrix allows for the direct formation of the desired shape as the matrix undergoes a hardening process over time, known as curing. This approach offers the potential for enhanced panel properties, including increased strength and flexibility, improved formability, and reduced weight and cost. These body panels in our case are made for SAE BAJA competition, SAE BAJA is an annual collegiate design competition organized by the Society of Automotive Engineers (SAE) in which teams of engineering students design and build single-seat, all-terrain vehicles (ATVs) to race off-road. The competition is held in the United States, Canada, Mexico, Brazil, and India. The goal of the competition is to design and build a safe, reliable, and durable ATV that can withstand the rigors of off-road racing. The vehicles are judged on their design, performance, and cost-effectiveness. SAE BAJA vehicles are designed to be lightweight, maneuverable, and capable of handling a variety of terrain, including sand, mud, and rocks.. We have highlighted a specific use case of the composite panels however they can be used for different applications too. The body panels used to cover the vehicle shown in the above vehicle are made of glass – fiber.

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Figure 1: Photo of SAE BAJA Car with composite body panels at e-BAJA 2023

1.3 Objectives

The primary objectives of the research paper are threefold, each focusing on a critical aspect of the design and analysis of composite body panels. The first objective focuses on the design of composite body panels. This involves a comprehensive understanding of the rulebook constraints and vehicle requirements that govern the design process [2]. The design phase also necessitates the calculation of the required thickness of the panels. This calculation is based on governing equations and considers the plane stress condition, which is a common assumption for thin panels. The design process aims to create panels that not only meet the specified requirements but also optimize performance and efficiency. The second objective involves the development of a mathematical model for the Tsai-Wu failure criterion. This criterion is a critical factor in the design and analysis of composite materials, as it predicts the point of failure under complex stress conditions. The objective includes calculating the failure criterion for the point of maxima, which represents the maximum stress state that the material can withstand before failure. The development and application of this mathematical model aim to enhance the reliability and safety of the composite body panels. The third objective focuses on the validation of the panel design using Finite Element Analysis (FEA) software. This involves calculating the maximum stress and strain regions within the panel, which are critical for assessing the panel's performance under load. The FEA also aids in computing the results using the Tsai-Wu failure criterion for the panel, providing a comprehensive analysis of the panel's performance and safety. The validation process aims to ensure that the design is robust and reliable, and that it meets the specified performance and safety standards. In summary, the research paper aims to design efficient and reliable composite body panels using mathematical modelling and FEA, adhering to rulebook constraints and vehicle requirements, and ensuring safety and performance through the application of the Tsai-Wu failure criterion. The paper strives to contribute to the body of knowledge in the field of composite materials and their applications in vehicle design.

Material Selection

The focus of this research paper is on the various types of fiber materials utilized in the fabrication of composite structures. These fibers encompass carbon, aramid (Kevlar™), polyethene, and boron fibers. However, the most prevalent fiber employed in Fiber Reinforced Polymers (FRP) is E-glass, which is also utilized in electrical insulation.

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E-glass [3] is a cost-effective and robust material produced by melting glass marbles and extruding the molten glass through hundreds of minuscule apertures. The resulting strands are reduced in diameter by applying tension as they are wound onto a storage reel, with diameters ranging between $\frac{1}{1000}$ to $\frac{5}{10000}$ of an inch. Virgin E-glass exhibits strength two to three times greater than alloy steel, although the processes of coiling and twisting yarn and weaving these yarns into fabric diminish their strength. Upon forming the laminate with the resin, it exhibits stiffness one-tenth that of alloy steel and one-fourth that of aluminium alloys. E-glass composites can endure substantial force, but they deform significantly under load. One advantage of E-glass over metals is its weight and superior stiffness-to-weight ratio. In addition to E-glass, several other types of fiberglass are used, such as S-2 Glass™, Carbon Fiber, Aramid (Kevlar™) Fiber, and Spectra Fiber™. The type of weaving, or fiber finish, also plays a crucial role in the strength and stiffness of the fiberglass laminate. Various types of weaves include Twill Weave, Five Harness Satin Weave, Crowfoot Satin, Plain Square Weave, Mat, and Veil. For the purpose of enclosing the structure of the roll cage with minimal protection from dirt and water, E-glass based on the Mat and Veil (a type of non-woven mat) was used. This type of non-woven glass cloth is less expensive and exhibits isotropic strength and stiffness characteristics, but has inferior stiffness characteristics due to the very short length of the fiber strands and their random placement within the cloth. For the fabrication of body panels, 300 GSM Chopped Strand fiberglass was used having a single ply thickness of 0.15 mm.

In the context of this research, particular attention is given to the resin used for binding the fiberglass panels. Specifically, Epofine 1564 resin [4] and Finehard 3486 hardener [5] are employed. Epofine 1564 is a versatile resin that can be paired with a variety of hardeners to achieve the desired properties. It is characterized by its high strength, resistance to high temperatures, and resilience against chemicals and solvents. On the other hand, Finehard 3486 is a colourless, low-viscosity, modified amine hardener. When used in conjunction with Epofine 1564, it forms a two-component epoxy resin system. Notably, Finehard 3486 exhibits excellent water resistance, making it a suitable choice for applications where exposure to moisture is a concern. The curing process is a critical aspect of the fabrication of composite body panels. In this research, the Room Temperature Cure (RTC) technique is utilized [3]. This technique is the most common curing method due to its simplicity and effectiveness. The resin and hardener are mixed at room temperature and allowed to cure without the need for additional heat. RTC resins are typically used for applications where a quick cure is required, such as bonding or sealing. It is important to note that the curing time is inversely proportional to the temperature; as the temperature increases, the curing time reduces. This relationship is a fundamental principle in the curing of resins and plays a crucial role in determining the efficiency of the fabrication process. In conclusion, the selection of resin and hardener, as well as the curing technique, are critical factors in the design and fabrication of composite body panels. These elements not only influence the physical properties of the panels but also impact the efficiency and cost-effectiveness of the fabrication process. Future research could explore alternative resins, hardeners, and curing techniques to further optimize the design and fabrication of composite body panels.

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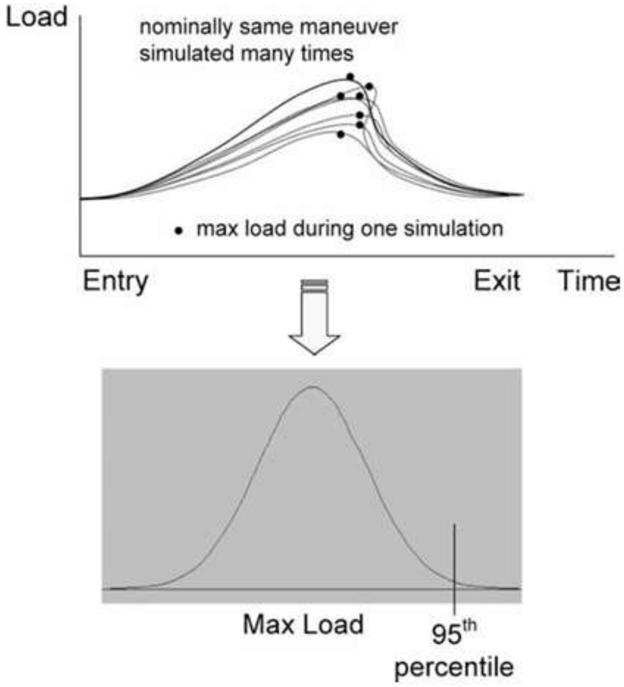

Figure 2: Selection of Applied Load after simulation using normal distribution [2]

While selecting the composite material, the material scatter factor must be taken into consideration along with the effects of environment as composite materials in their curing stage are sensitive to changes in environmental conditions. As temperatures and moisture levels rise above room temperature, the strength and stiffness of materials decrease. Reduced temperatures result in reduced strength qualities compared to room temperature. The strength of the material employed in a design is not a fixed value. Material variability can be caused by inherent microstructure, batch variance, fabrication method (e.g., curing cycle), and other factors. Geometry within tolerances, such as thickness variation within the same specimen, can result in varying strength ratings when testing the same nominal geometry and layup. To avoid scenarios when the material's strength falls below the statistical distribution, designs must account for variance. For this aim, precise statistically significant values are chosen that are assured to be lower than the maximum value and we chose value in the 95th percentile.

For the design of body panels, we go with the B-Basis [2] value i.e., tenth percentile of the population which means that 90% of the samples in the test will have strength greater than or equal to the B-Basis value. The A- and B-Basis values are calculated based on statistical methods accounting for batch-to-batch variation, the type of statistical strength distribution, and the number of data points. The reason for selecting B-Basis over A-Basis is the fact that body panels used in the ATV are providing protection from external agents and the vehicle will not cease to function even if they are heavily damaged.

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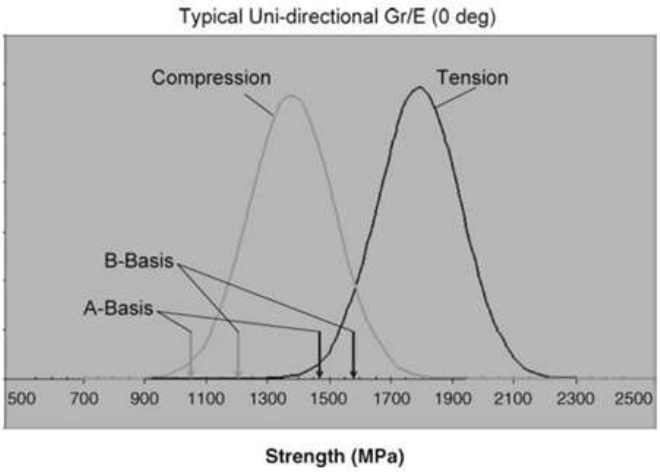

Figure 3: Range of values for different Basis [2]

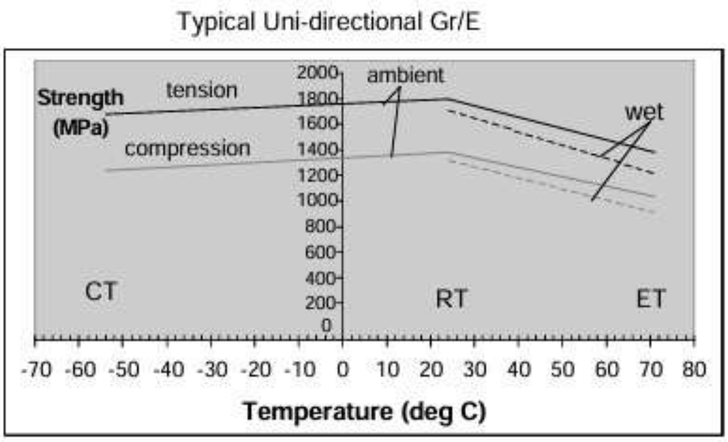

Figure 4: Variation of tension and compression as a function of temperature and moisture [2]

2. RELATED WORK

The article on composites materials [1] gives us a clear idea of application of the composite materials and where it can replace the traditional materials. Studies of Christos Kassapoglou [2] demonstrates the different types of loading on different composite fibre materials and how the load distribution is done on these fibres. Using these studies, we can understand why the load value on 95th percentile is selected. The book by Forbes Aird [3] is a general-purpose book which gives all the methodologies for composite material part fabrication and using the datasheets of epoxy resin [4] and epoxy hardener [5], we acquired the material properties required for the model. The paper by Guo et al. [6] explains the mechanics of curing required for composite materials and how it differs based on the type of structure. From Kangal et al. [8], we have obtained the directional properties of E-glass required for the mathematical model and the FEA model. The Tsai-Wu model is an extended or a modified version of the general quadratic formulation presented by Gol'denblat and Kopnov [9]. The article by Solidworks [10] is used to refer the formulation and the studies of Ounis et al [11] is used to define the co-

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ordinate system used for analysis of composite panels. The paper by Goodship et al [12] is used to understand the Lay-Up process and how it can be implemented for the body panels.

3. METHODOLOGY

The process of design of body panels involves major aim of compliance with the rulebook for the SAE BAJA competition which governs the thickness factor for the panels and according to our objective, it must be lighter than the metal counterparts for the same size and must have good enough stiffness to resist external agents such as water, pebbles, dirt, gravel, etc. We also perform structural analysis which is crucial to ensure that panel can withstand the required loads and stresses along with implementation of quality control measures to ensure consistency throughout all the panel sections.

3.1 Force Analysis

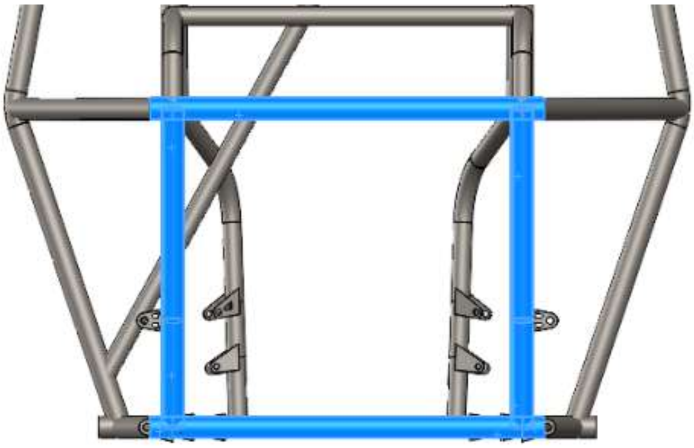

Figure 5: Front Bulk Head, indicated using blue highlight [7]

For the front bumper section known as the "Front Bulk Head"[7], we will create a composite panel capable of protecting the inner components and driver from dirt, water, stones, and other obstacles as the vehicle travels through rough terrain. The Lay-Up process will be used to create these panels, which will be cured at room temperature. Dimension A is 470 mm and Dimension B is 430 mm and thickness is 0.5 mm and this is the thickness governed by rulebook constraints [7], so a 3 layered structure (3-ply) of fiber-epoxy setup will be used. The bolting holes are of diameter 4 mm and for analysis, we shall use the sides of the body panel to be fixed. This was done because the body panel will also be supported by the tubes of the roll cage.

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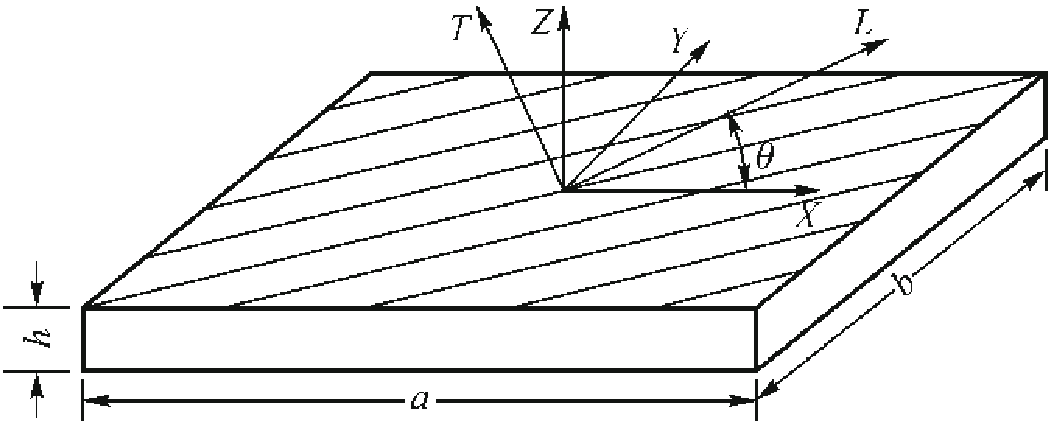

Figure 6: Geometry and co-ordinate system of the composite plate [11]

Drag Force and Total Force Calculations:
Frontal Area (A) = $430 \times 470 = 2{,}02{,}100 \text{ mm}^2$
Drag Coefficient (C_d) =0.35, average values for cars
Density of Air (ρ) = 1.293 kg/m^3
Maximum Velocity (v) =10 m/s, maximum speed of SAE BAJA cars
Drag Force (F_d) = $0.5 \times \rho \times v^2 \times C_d$ (Eq. 1)
$F_d = 4.573$ N

Consider a static stone hits the front panel of the roll cage, consider weight of the stone to be 1 kg and vehicle hits the stone with a speed of 10 m/s, using the energy conservation equation and we assume that entire kinetic energy of stone is absorbed by the potential energy of the composite panel.

Mass of stone (M_s) = 1 kg
Velocity of car (v) = 10 m/s
Kinetic Energy = $0.5 \times M_s \times v^2$ (Eq. 2)
Kinetic Energy = 50 Nm
Kinetic Energy = Potential Energy
Potential Energy = $F \times d$ (Eq. 3)

Assuming maximum d =20 mm, this is the threshold for panel deformation (d).
$50 = F \times 0.02$
$F = 2500$ N
Total Force = $Fd + F = 4.573 + 2500 = 2504.57$ N in direction of - Z axis
Now the entire force is assumed to be distributed equally among the surface of the body panel. So, the Force per unit area on the panel will Total Force by area of panel.
Pressure (P) = F/A
$P = 13377 \text{ N/m}^2$ in the direction of z – axis

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Table 1: Properties of E-Glass [8]

Symbol	Description	Glass fiber/epoxy Value
E_1	Longitudinal (fiber dominated) modulus (GPa)	38.5
E_2	Transverse (matrix dominated) modulus (GPa)	16.5
$v_{12} = v_{13}$	Poisson's ratio (in plane)	0.27
v_{23}	Poisson's ratio (planed 2-3)	0.40
$G_{12} = G_{23}$	In-plane shear modulus (GPa)	4.7
G_{23}	Out-of-plane shear modulus (GPa)	4.7
X_t	Longitudinal (fiber dominated) tensile strength (MPa)	1250
X_c	Longitudinal (fiber dominated) compressive strength (MPa)	-650
Y_t	Transverse tensile (matrix dominated) strength (MPa)	36
Y_c	Transverse compressive strength (MPa)	-165
S_{12}	In plane shear strength (MPa) (tensile)	86
S_{21}	In plane shear strength (MPa) (compressive)	-86
Negative sign represents opposite direction		

Calculation of panel thickness (t) using analytical method:

$$t = \frac{(F \times (1 - v^2))}{(A \times E)} \quad \text{(Eq. 4)}$$

Area (A) = 202100 mm^2
F = 2504.57 N
Considering the longitudinal (fiber dominated) plane,
E = 38.5 GPa
v = 0.27

The minimum thickness required (t) is in terms of 10^{-4} mm and so the design thickness of 0.5 mm is sufficient for our case.

4.2 Failure Criterion

We applied the Tsai-Wu failure criterion to composite materials. The Tsai-Wu criterion predicts failure when the failure index in a laminate reaches one. This failure criterion is a specialization of the general quadratic failure criterion proposed by Gol'denblat and Kopnov [9]. It can be expressed in the following form: where F_i and F_{ij} are experimentally determined material strength parameters.

$$F_i\sigma_i + F_{ij}.\sigma_i.\sigma_j \leq 1 \quad \text{(Eq. 5)}$$

Tsai-Wu failure criterion for orthotropic materials considers the total strain energy (both distortion energy and dilatation energy) for predicting failure. It is more general than the Tsai-

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Hill failure criterion because it distinguishes between compressive and tensile failure strengths. [10] The stress state of lamina calculated by the program is described by the components: σ_1, σ_2, and τ_{12}

σ_1 - laminate stress along fiber direction

σ_2 - laminate stress transverse to fiber direction

τ_{12} - laminate shear stress

$$F_1\sigma_1 + F_2\sigma_2 + 2F_{12}\sigma_1\sigma_2 + F_{11}\sigma_1^2 + F_{22}\sigma_2^2 + F_6\tau_{12} + F_{66}\tau_{12}^2 = 1 \quad \text{(Eq. 6)}$$

$$F_1 = \left(\frac{1}{X_T} - \frac{1}{X_c}\right)$$

$$F_2 = \left(\frac{1}{Y_T} - \frac{1}{Y_c}\right)$$

$$F_{11} = \frac{1}{X_T \times X_c}$$

$$F_{22} = \frac{1}{Y_T \times Y_c}$$

$$F_{12} = -\frac{1}{2}\sqrt{\frac{1}{X_T \times X_C} \times \frac{1}{Y_T \times Y_c}}$$

$$F_6 = \left(\frac{1}{S_{12}} - \frac{1}{S_{21}}\right)$$

$$F_{66} = \frac{1}{S_{12} \times S_{21}}$$

The above equation is applicable for 2D structures (plane stress).

Meshing

In the computational study presented herein, the automesh feature of FEA software played a pivotal role in the precise delineation of the panel structure’s geometry. The feature was particularly effective in representing the minuscule holes, which are markedly smaller than the overall dimensions of the panel. The inherent simplicity of the part’s design facilitated the automesh function’s ability to accurately capture and incorporate it into the computational model. This advanced capability eliminated the necessity for manual meshing of each individual geometric feature, thereby significantly expediting the mesh generation process. Furthermore, it ensured that the computational representation adhered closely to the actual physical form of the component, thereby enhancing the accuracy of subsequent simulations. Mesh convergence is not required in this case because the automesh feature in FEA software has been able to accurately capture the geometry of the part due to its simplicity. When the geometry is straightforward and the mesh generated by the automesh feature is of high quality, it can be assumed that the mesh is sufficiently refined to accurately represent the physical model without further refinement.

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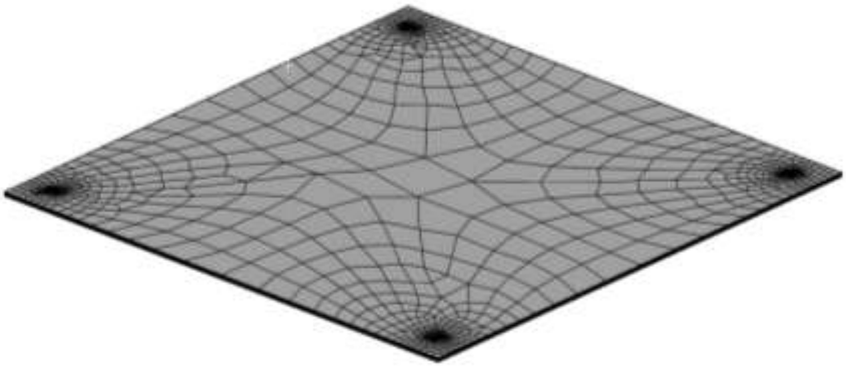

Figure 7: Meshed panel using automesh feature

In finite element analysis using automesh, critical mesh parameters must be rigorously evaluated to ensure model accuracy. Element quality is essential, with a focus on avoiding disproportionate aspect ratios that may affect results. Element shape should not be distorted, as it influences solution precision. Mesh density is vital in high-stress areas to capture details accurately. Node connectivity and correct boundary condition application are necessary to prevent mesh issues and ensure reliable simulations.

Manufacturing Process
Step 1: First select a plain and even surface like glass to lay the fibre glass and before laying the fibre glass, use the release agent to clean the surface and allow it to air dry.

Step 2: Combine epoxy in the specified ratio. It is important to combine the hardener and resin gradually and thoroughly, being careful not to trap any air bubbles.

Mix Ratios
Mixed Epoxy weight: Fiber weight = 1:1
Resin: Hardener = 3:1
Using mix ratios, calculating required resin/Hardener:
$Hardener\ weight\ =\ Fiber\ weight \div 4$
$Resin\ weight\ =\ Hardener\ weight\ \times\ 3$

Step 3: Organize for the layup procedure [12], we might use our hands or a squeegee. Apply a thin layer of blended epoxy. It is crucial to use enough epoxy in the initial layer since it facilitates easy removal. Next comes placing the first layer of fibre, followed by another layer of mixed epoxy that is spread out using your hands. Make every ply as clear and resin-saturated as possible. There should to be no white areas. Applying the second coat in a similar manner, then the third. Pour in enough epoxy. The arrangement needs to be weighted down and left to dry for a full day. The body panel should be removed by separating the weight with a sharp knife once it has dried.

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4. RESULTS AND DISCUSSION

4.1 Mathematical Model

The Tsai-Wu failure criterion is a cornerstone in the field of composite material analysis, offering a nuanced approach to predicting failure under complex stress states. Unlike simpler failure theories that consider stress components in isolation, the Tsai-Wu criterion acknowledges the synergistic effects of different stresses acting on a material. The formulation of this criterion is rooted in a quadratic polynomial that accounts for the interaction between normal and shear stresses, as well as their respective strengths in various directions relative to the fibers. This polynomial is calibrated such that a value of one indicates impending failure, providing engineers with a precise threshold for safety and design optimization. In applying this criterion computationally, our model meticulously decomposes the applied force into its orthogonal stress components based on the laminate's orientation. This decomposition is crucial as it allows for an accurate representation of the stress state within the laminate, which can vary significantly with orientation due to anisotropy inherent in composite materials. The model then inputs these stress components into the Tsai-Wu polynomial, which includes terms for material strengths and interaction coefficients. The discretization factor plays a pivotal role here, mimicking a finite element analysis by segmenting the laminate into smaller patches. This segmentation enables a more granular simulation of stress distribution, ensuring that local variations in stress are captured and factored into the failure analysis.

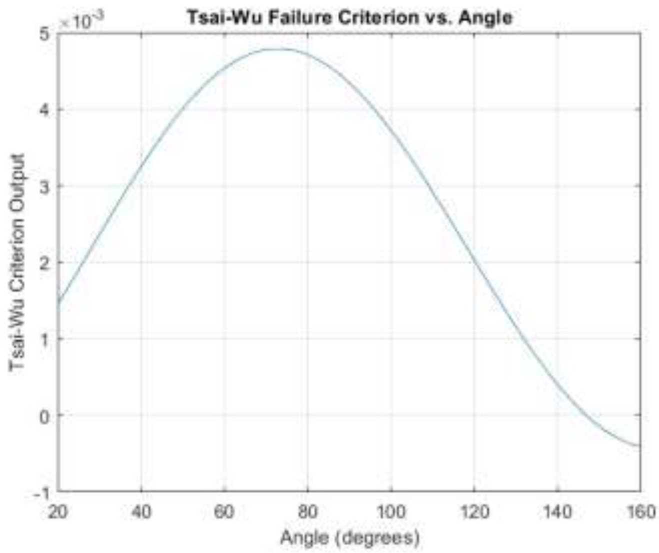

Figure 8: Tsai-Wu Failure Criterion values for the given load for range of angle

The practical implications of this model are profound. By accurately simulating how composite laminates behave under different loading conditions, engineers can predict potential failure points and adjust design parameters accordingly. This predictive capability is invaluable in industries where material failure can have catastrophic consequences, such as aerospace and automotive engineering. Moreover, by optimizing composite structures based on Tsai-Wu failure predictions, material usage can be minimized without compromising safety, leading to

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cost savings and efficiency gains. The model's ability to output only the maximum value of the Tsai-Wu criterion for each discretized patch ensures that engineers can identify the most critical areas for intervention, streamlining the design process and enhancing overall structural integrity. The model will compute the Tsai-Wu failure criterion for the discretized patch where the load is applied so that it will only output the maximum value. The formulation used for the failure criterion requires substitution of strength values along with the positive and negative sign i.e., positive for tension and negative for compression. The model will also output Tsai-Wu failure criterion values with respect to angles ranging from 20° to 160°.

4.2 Finite Element Analysis

For FEA, ANSYS software was used due to its robust finite element analysis capabilities, accurate material modelling options, and the ability to integrate the Tsai-Wu failure criterion. ANSYS Workbench's ACP feature is used to model the FE simulation of composite material.

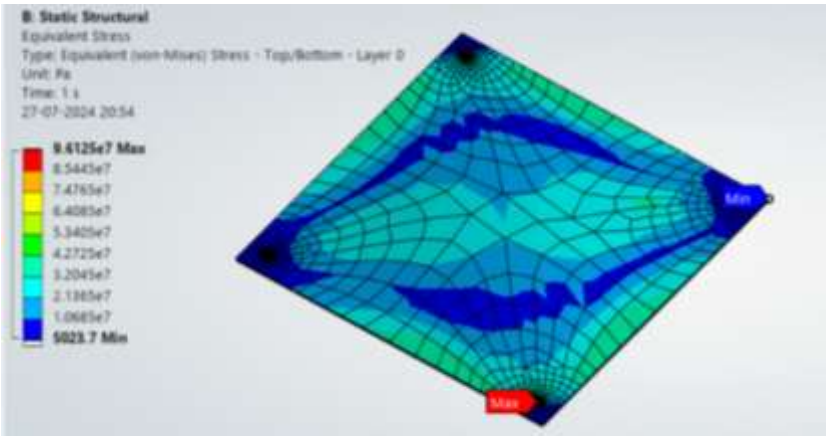

Figure 9: Equivalent Von Mises Stress in Pascals

For Von Misses Stress, the maximum stress is around the four bolting points on the panel and rest of the stress is distributed evenly throughout the panel. The stress value over the entire panel is around the minimum stress value and the average value of stress is 8.25 MPa.

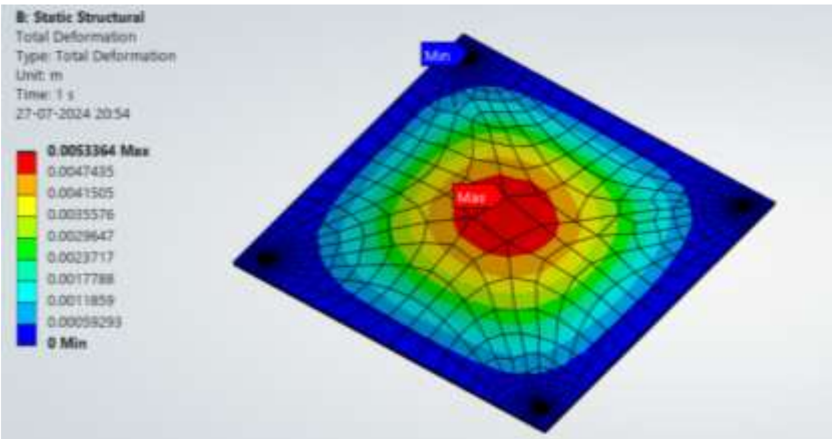

Figure 10: Total Deformation in m

Journal of Electronics, Computer Networking and Applied Mathematics
ISSN: 2799-1156
Vol: 04, No. 05, Aug-Sept 2024
http://journal.hmjournals.com/index.php/JECNAM
DOI: https://doi.org/10.55529/jecnam.45.1.15

The total deformation of the structure is maximum at the center of the panel as expected and the lowest deformation is found near the bolting points.

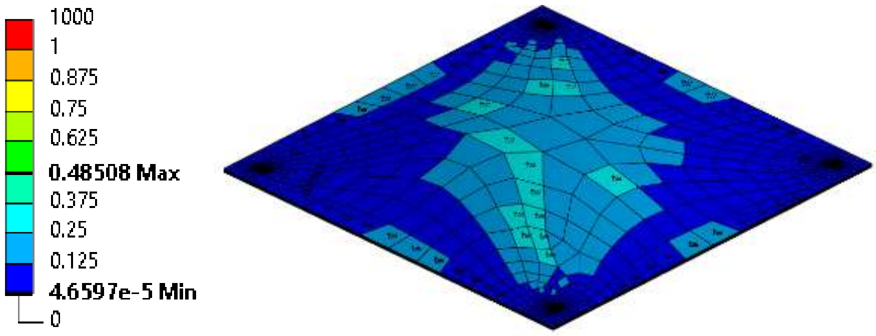

Figure 11: Tsai Wu Failure Criterion

We can observe from the figure that the panel passes the Tsai-Wu failure criterion and the value of $F_i\sigma_i + F_{ij}.\sigma_i.\sigma_j$ is always less than 1 (Maximum value is 0.485). So, the panel design is safe.

5. CONCLUSION

In conclusion, the comprehensive investigation into the design, analysis, and manufacturing of composite body panels for the SAE BAJA vehicle has yielded promising results. The transition from conventional materials to E-glass, specifically 300 GSM Chopped Strand fibreglass, showcases the potential of composite structures to replace costlier and heavier alternatives. The meticulous material selection, incorporating Epofine 1564 resin and Finehard 3486 hardener, coupled with the Room Temperature Cure (RTC) technique, establishes a practical and efficient fabrication process. The application of the Tsai-Wu failure criterion in finite element analysis (FEA) ensures the structural integrity of the designed panels under various loading conditions, affirming their safety and reliability for enclosing the roll cage structure in off-road racing scenarios.
This study's success lies not only in the theoretical considerations but also in the hands-on methodology, from surface preparation to the lay-up process. The integration of ANSYS Workbench's ACP feature for FEA provides valuable insights, validating the composite panels' performance. The calculated pressure distributions and force analyses align with safety standards and competition requirements. This research contributes a comprehensive guide for engineering teams engaging in similar challenges, fostering the adoption of composite materials in off-road vehicle design and, potentially, in broader automotive applications. The success of this endeavour opens avenues for further exploration, optimization, and innovation in composite structures within the realm of engineering design.

6. REFERENCES

1. Article on Composite Materials
2. Christos Kassapoglou, "Design and Analysis of Composite Structures", Delft University of Technology.

Journal of Electronics, Computer Networking and Applied Mathematics
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http://journal.hmjournals.com/index.php/JECNAM
DOI: https://doi.org/10.55529/jecnam.45.1.15

3. Forbes Aird, "Fiberglass & Composite Materials: An Enthusiast's Guide to High Performance Non-metallic Materials for Automotive Racing and Marine Use", (1996)
4. Fine- Finish Organics Pvt. Ltd. "Epofine 1564" product datasheet
5. Fine- Finish Organics Pvt. Ltd. "Finehard 3486" product datasheet
6. Guo, Zhansheng & du, Shan-Yi & Zhang, Boming & Wu, Zhanjun. (2006) "Cure Characterization of a New Bismaleimide Resin using Differential Scanning Calorimetry", Journal of Macromolecular Science, Part A: Pure and Applied Chemistry. 1687-1693. 10.1080/10601320600938942.
7. SAE INDIA (2023): "SAE e-BAJA 2023" Rulebook
8. Kangal, Serkan & Kartav, Osman & Tanoglu, Metin & Aktaş, Engin & Artem, H. (2019), "Investigation of interlayer hybridization effect on burst pressure performance of composite overwrapped pressure vessels with load-sharing metallic liner"
9. Gol'denblat, I. and Kopnov, V. A. (1966), "Strength of glass reinforced plastic in the complex stress state" Polymer Mechanics, vol. 1, pp. 54–60. (Russian: Mechanika Polimerov, vol. 1, pp. 70–78. 1965)
10. Solidworks Article on Tsai-Wu
11. Ounis, Houdayfa & Tati, Abdelouahab & Benchabane, Adel. (2014), "Thermal buckling behaviour of laminated composite plates: A finite-element study"
12. Vannessa Goodship, Bethany Middleton, Ruth Cherrington, "Design and Manufacture of Plastic Components for Multifunctionality", William Andrew Publishing, 2016, Pages 53-101, ISBN 9780323340618, https://doi.org/10.1016/B978-0-323-34061-8.00003-X.