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Conceptual Structural Optimization and AI-Based Stress Prediction of a Monocoque Chassis for Formula Student Electric Vehicle

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Abstract— **This study presents the conceptual design, optimization, smart material assessment, and ai based stress prediction of the monocoque chassis of the Formula Student Electric Vehicle (FSEV). The chassis designed according to the 2025 Formula Student guidelines focusing on high structural compliance and safety, stiffness, and minimal weight [1],[2]. A total of 14 engineering materials were compared and analysed structurally for their performance in regards to impacts. The material selection was done based on the finite element analysis (FEA) simulations of front and rear impacts concerning total deformation. Only the most favourable material was selected based on the FEA simulations of the front and rear impacts [3],[4]. A detailed computer-aided design (CAD) model created on SolidWorks, and ANSYS Workbench was used to conduct the FEA for front, rear, and side impacts. Through iterative topology optimization, unnecessary materials were eliminated to the maximum degree while ensuring that the structure remained crashworthy. The result of the optimization process on the CFRP monocoque is a weight reduction of 35-40% while ensuring that high stiffness and safety requirements are met compared to the conventional spaceframe. An AI regression model for stress prediction has been created as a method for increasing efficiency. Using Young's modulus, yield strength, and Poisson's ratio as inputs, the model has been shown to reduce the number of simulations needed for stress distribution predicting and accelerate the process of selecting materials. The combination of AI and FEA has created a solid, time-saving approach to the design of chassis. The research suggests that AI modelling and CFRP monocoques provide next generation Formula Student electric vehicles with improved safety, better efficiency, and cost-effective alternatives to competitors with high stiffness-to-weight ratios [2].**

Keywords— FSEV, Monocoque Chassis, Spaceframe, Carbon Fiber Reinforced Polymer (CFRP), Torsional Stiffness, Crashworthiness, Finite Element Analysis (FEA), Artificial Intelligence (AI), Regression Model, Stress Prediction.

I. INTRODUCTION

The chassis is the main structural component of a Formula Student vehicle, and is responsible for rigidity, crashworthiness, and the integration of vital components like suspension, powertrain, and driver ergonomics. In the case of FSEVs, focusing on lightweight construction and energy efficiency has made chassis optimization a focal point of development [5],[7].

Steel tubular space frame chassis have gone in because of their put together design, low price, and easy production. But they do tend to be heavy, have many weld points, and perform poor in terms of stiffness which in turn affects handling and energy efficiency. In contrast the monocoque chassis with particular use of CFPR which uses the vehicle body to also bear the structure. This approach improves weight reduction, increases torsional stiffness, improves crash energy absorption, and does better at putting components all in one structural unit thus doing away with the need for extra support structures [8], [9].

It also proposes a new methodology to combine material selection, and AI-based stress prediction for a monocoque chassis. Using Finite Element Analysis (FEA), a comparative study of 14 engineering materials was performed, and the most suitable material was selected based on total deformation under front and rear impact conditions. Additional FEA was conducted for front, rear, and side impacts to study the distribution and deformation behavior of stress.

An AI-based regression model was created using a subset of 100 materials from the FEA simulations. The model, using the properties of materials as an input, predicts stress in the chassis, thus reducing the number of simulations performed and accelerating design iterations.

In a study by Margareth et al. [1] they looked at CFRP monocoques which they reported to have a 40-60% weight reduction over metal frames which at the same time preserved the same stiffness which they attributed to the fiber orientation and laminate stacking. Also in the work done by Davies et al. [2] illustrated an aluminium honeycomb sandwich monocoque for use in the Formula Student which achieved 2300 to 2500 Nm/deg in terms of torsional stiffness and a total mass of less than 220 kg which demonstrated a proof of of cost-effective and lightweight chassis solutions.

Advancements in composite technology which in turn saw growth of their use in solar and electric vehicles. Denny

et al. [11] presented a study on a solar vehicle monocoque via FEA in Siemens NX Nastran which attainment of 4097 Nm/deg in torsional stiffness and also an improved crash load distribution. Tsirogiannis [13] reported a CFRP–epoxy chassis designed through parametric CAD and the rule of mixtures, resulting in an 82 kg structure with an energy efficiency of 63 km/kWh, thereby illustrating the potential of lightweight, high-strength configurations Also Airale et al. [7] examined the use of CFRP in hydrogen prototypes which they validated through experimental and numerical testing and reported very good specific stiffness and impact resistance.

This research work stands out due to its integration of structural topology optimization, careful material selection, and finite element analysis validation applied to a CFRP monocoque chassis designed for a FSEV. This study demonstrates the correlation between weight reduction and the energy efficiency of the vehicle, illustrating how lower mass facilitates rapid acceleration, improves control, and boosts performance in various dynamic aspects. This resulted in a CFRP monocoque chassis that is both lightweight and offers high stiffness, tailored to the needs of Formula Student. The workflow of designing formula student vehicle is shown below.

Flow Diagram

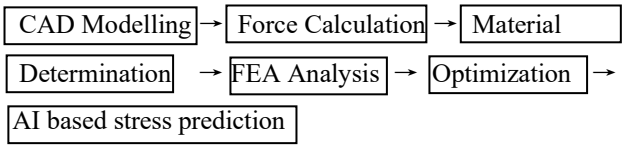


Fig. 1. Work flow

The workflow (Fig.1) of the project follows a systematic approach as shown in flow diagram. The chassis geometry developed by considering design standardization, ergonomics and topology optimization. force calculation defined loading condition for accurate simulation. Material selection ensured high strength to weight ratio, energy efficient and fatigue resistance. using FEA, multiple iteration was conducted to enhance stiffness and structural integrity. through continuous optimization a 35% to 45% weight reduction achieved (18.33 kg vs 35 kg), resulting in a lightweight, durable, efficient chassis for electric vehicle application. The AI model, using the properties of materials as an input, predicts stress in the chassis, thus reducing the number of simulations performed and accelerating design iterations.

II. PROPOSED METHODOLOGY

The proposed CFRP monocoque chassis construction for a FSEV followed a detailed approach that considered regulations, structure, and ease of manufacture. This included design standardization, CAD, material studies, and simulation. Each stage aimed for the best possible compromise on safety, stiffness, and weight. The approach consisted of four stages. The design of the chassis followed the Formula SAE/Formula Student 2025 Rulebook and included the requirements for impact attenuation and safety cell dimension, roll-over protection, and battery shielding. The final geometry also included ergonomic considerations with respect to the driver's entry and exit, sight, and the positioning of the pedals and the steering which contributes to the driver's safety, comfort, and overall operational efficiency in dynamic driving. A comprehensive 3D CAD model had been engineered in SolidWorks, focusing on recognizing correct load paths, and on the ease of integration of the suspension with the aerodynamic subsystems. The design strategy aimed for the best combination of mass and stiffness, and included structural topology optimization, which would be followed by FEA validation and an assessment on the model's manufacturability. In selecting suitable materials for the chassis, 14 materials were considered, as one can study the structural response of various materials to different energy levels for the design of crashworthy structures. Finite Element Analysis (FEA) was done on the materials for front and rear impacts to see how the materials performed in regards to maximum total deformation. Carbon Fiber Reinforced Polymer (CFRP) was ranked the highest in the study because of its being the best for stiffness to weight ratio and for energy absorption as well as fatigue resistance [1], [2], [8]

A tetrahedral mesh structural analysis suited for complex geometries was created for the monocoque chassis analysis. The mesh was refined around high-stress concentration areas such as suspension mounting points, battery housing interfaces, and load application zones for accurate stress prediction. An average mesh element size of 1 mm was used. To conduct a mesh-independence study, the chassis was analyzed under identical loading conditions with three different mesh densities: coarse, medium, and fine. The maximums of von Mises stress and total deformation were compared, and the changes between the medium and fine meshes were found to be less than a specific threshold, indicating mesh convergence. Thus, for the final analysis, the medium-density mesh was chosen to balance accuracy and computational cost. To validate the analysis, the maximum von Mises stress obtained from the finite element analysis was compared with the limiting stress of CFRP material, and the results demonstrated the calculated stress was lower than the limiting stress, confirming the design is structurally safe under the given loading conditions.

A chassis stress predictive model using AI regression is being developed over the need for many repeated simulations. A data set from FEA for 100 different materials and their mechanical property variations and stress responses will be part of the data for the model.

The AI inputs are

1. Young's Modulus
2. Yield Strength
3. Poisson's ratio

Under specific loading conditions, the chassis predictive stress response is the AI model's output. The model can quickly evaluate other materials as it is developed and validated for high prediction accuracy, thus eliminating the need for a complete FEA.

III. PRIMARY DESIGN MODEL

The monocoque chassis with SolidWorks had as its' goal to achieve an ideal balance between structural rigidity, safety, and lightweight construction which in turn followed the Formula SAE/Formula Student 2025 rules. the design process includes determining the driver's seat position, pedal and steering wheel layout which at the same time had to meet ergonomic standards of easy in and out, driver comfort

and field of vision. These parameters in turn dictated the basic geometry of the safety cell and also played a role in the placement of the front bulkhead, roll cage, and firewall [13].

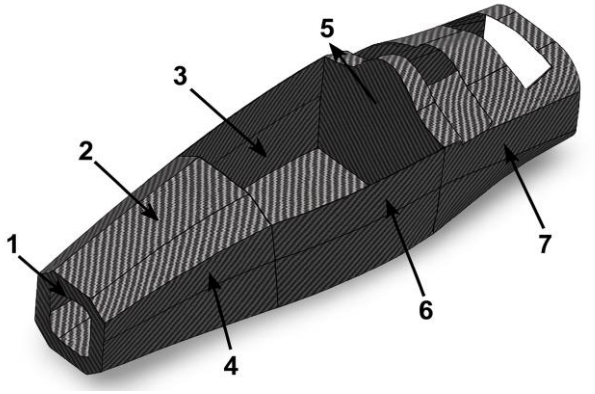


Fig. 2. Design Model

The CAD model of the chassis (Fig. 2) consists of seven components arranged sequentially: (1) Front Bulkhead, (2) Front Hoop, (3) Compartment, (4) Front Bulkhead Support, (5) Main Hoop, (6) Side Impact Support, and (7) Battery Pack with Transmission Space. The chassis measures 2125.4 mm in length, 623.2 mm in width, and 714 mm in height, optimized for strength, compactness, and driver safety in a FSEV.

The monocoque which has a integral structural shell that also serves as the primary load bearing element and safety cell which in turn does not require a separate frame. In this design it includes front and rear distinct impact structures for efficient crash energy absorption which in turn reduces transfer of forces to the cockpit. The front of the car is designed to provide a progressive energy absorbing zone during frontal impacts and the rear structure supports the motor mounts, suspension and energy storage systems. Localized thickness variations are implemented in these regions to enhance crash performance while avoiding any significant increase in overall weight.

CFRP is used in the chassis for its low density (≈1.6 g/cm³), high strength (550–1100 MPa), and stiffness (70–150 GPa). Its excellent stiffness-to-weight ratio and energy absorption make it ideal for lightweight, high-performance monocoque structures in FSEVs.

IV. FORCE CALCULATIONS

Assumptions for Making the analysis computationally efficient and representative required several considerations. The most extreme dynamic impact conditions were reduced to static loads of 8G for the front and rear impacts and 6G for the side impacts. The carbon fiber material was treated as isotropic and homogeneous. The small deflection theory of a structure was applied, assuming there would be no significant changes in geometry during loading. The self-weight of the chassis was neglected because impact forces would always dominate. All supports were treated as perfectly rigid and immobilized in translation and rotation.

Boundary Conditions: During the front impact scenario, the rear suspension points were held fixed, while an 8G load was applied at the front bulkhead. In the scenario for rear impact, the front suspension points were fixed, and an 8G load was applied at the rear of the chassis. In the case of side impact, one side of the chassis was fixed, and a 6G load was applied to the side impact member.

A static structural analysis was carried out to evaluate the chassis under different loading conditions. In the front, rear, and side impacts manual calculation are performed for structural loading on the chassis during collisions. Considering vehicle's mass, impact speed, and break up distance to determine forces which obtained from Newton's second law and energy conservation principles. The calculated loads are applied in static structural FEA to provide realistic input conditions for accurate assessment of stress distribution and chassis deformation under impact loading.

TABLE I. FORCE CALCULATIONS

	Front Impact Analysis	Rear Impact Analysis	Side Impact Analysis
Vehicle speed (Vi)	29.16 m/s	29.16 m/s	22.23 m/s
Impact duration (t)	0.4 s	0.4 s	0.4 s
Vehicle mass (m)	280 kg	280 kg	280 kg
Final velocity (Vf)	0	0	0
F= m (Vi-Vf)/t	20.4 kN	20.4 kN	15.56 kN
G Force= F/(m×9.8)	6.94	6.94	5.29
G Force or Load	8G	8G	6G

V. MATERIAL SALECTION

The design of monocoque chassis is heavily impacted by the choice of materials, and influences the structural performance, weight, safety, and overall efficiency of the vehicle. The monocoque structure is unique in that it combines the frame and the body into a single load-bearing unit. Therefore, the materials used for construction have to provide high values of strength, stiffness, and energy absorption; all while being lightweight [1], [2], [8].

In order to optimize materials, a comparative evaluation of 14 materials in ANSYS Workbench simulation, for identical geometry, loading, and boundary constraints, was conducted. The key parameter for evaluation was total deformation, which represents structural stiffness and integrity in an inverse manner. The material characteristics; Young's modulus, yield strength, density, and Poisson's ratio, were taken as standard values. A comparative table of key material properties used for the analysis is presented below [15].

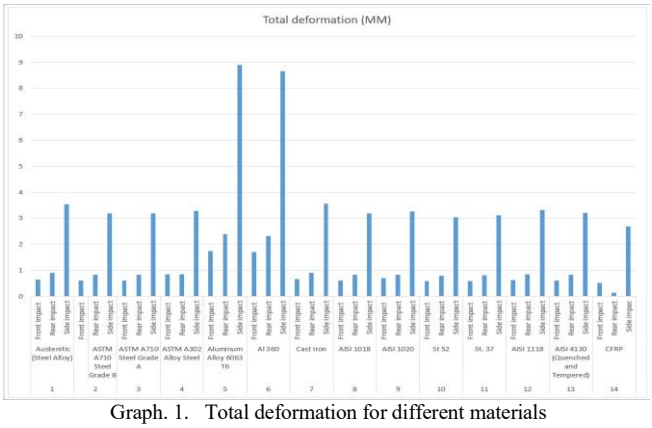
TABLE II. MATERIAL COMPARISON FOR CHASSIS DESIGN

S. No.	Material Name	Young's Modulus (GPa)	Yield Strength (MPa)	Poisson's Ratio
1	Austenitic Steel Alloy	193	290	0.25
2	ASTM A710 Steel Grade	205	585	0.29

	B			
3	ASTM A710 Steel GradeA	205	585	0.29
4	ASTM A302 Alloy Steel	200	345	0.29
5	Aluminium Alloy 6063-T6	69	215	0.33
6	Al 360	71	170	0.33
7	Cast Iron	190	241	0.26
8	AISI 1018	205	370	0.29
9	AISI 1020	200	351	0.29
10	St 52	210	355	0.31
11	St 37	210	350	0.29
12	AISI 1118	200	315	0.29
13	AISI 4130 (Q&T)	205	460	0.285
14	CFRP	150	1100	0.28

The results of the FEA deformation studies show that the stiffness of a material is an important factor in the overall performance of the structure in question. Less stiff materials, like aluminium alloys, show considerably greater deformation (over 8mm), and therefore would not be good choices for structures, such as the one described, that require the material to not experience a lot of deflection. Conventional steels have a reasonable deformation of 3-3.5mm, which corresponds with low deflection design of a structure that is designed to provide adequate strength and also a weight penalty.

Alloy steels of the type AISI 4130 perform better as a result of increased strength and therefore less deformation in comparison to the steels of the previous paragraph. They, however, are still not competing with materials of a similar type of construction as composites, in particular, with regards to the stiffness to weight ratio. The variation of total deformation for different materials under front, rear, and side impact conditions is illustrated in the graph below.



Graph. 1. Total deformation for different materials

It is clear from the graph that out of all the materials, CFRP has the least deflection at all load cases (front impact 0.5mm, rear impact 0.2mm and side impact 2.7mm). From this it can be concluded that CFRP has a greater stiffness and therefore a greater ability to properly distribute the load and resist the deformation in comparison to all the materials tested.

It is for these reasons that CFRP is chosen as the best material for the monocoque chassis. This is due to: high strength to weight ratios, least deflection (maximum stiffness), good absorbed energy capabilities, and the overall performance regarding rigidity, rotation and impacts

VI. FINITE ELEMENT ANALYSIS RESULTS

In the study static structural analysis performed for the Formula Student vehicle CFRP monocoque chassis in ANSYS Workbench which was done to assess its structural integrity in front, rear, and side impact. To enhance structural stiffness and minimize stress concentrations, Along with weight reduction design evaluation typically occurs in multiple iterations. For the analysis, load inputs are usually obtained from manually computed impact forces considering vehicle mass, velocity, and deformation parameters.

A. Iteration 1

The initial iteration presented the first chassis model created in SolidWorks. The analysis highlighted some design areas in need of optimization

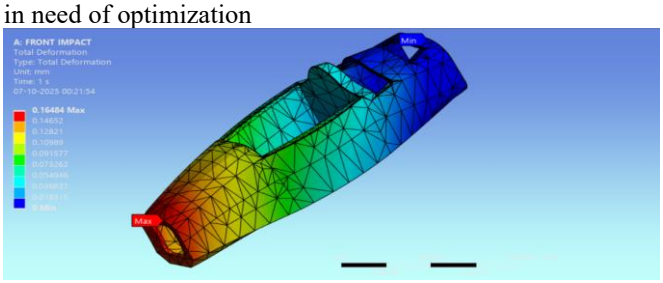


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Fig. 3. Front impact maximum deformation

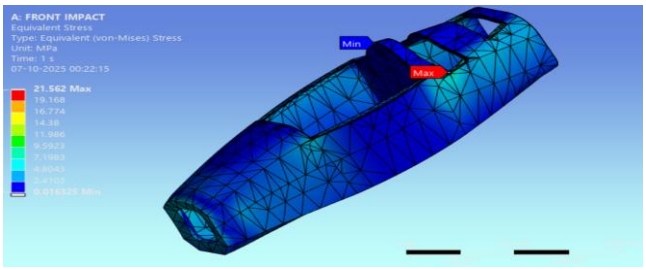

Fig. 4. Front impact maximum stress

Figures 3 and 4 illustrate that the frontal impact yields a maximum deformation of 0.033 mm. Stress captures a peak value of 21.58 MPa and remains concentrated around the front bulkhead and suspension mounting zones. These areas sustain the major impact loads since, in the simulation, the chassis rear-end is fixed. Thus, the front joints must absorb all the impact deceleration forces. The abrupt geometric transitions across the bulkhead create stress concentrators, while the overall heavy structure (183 kg) limits global. deflection

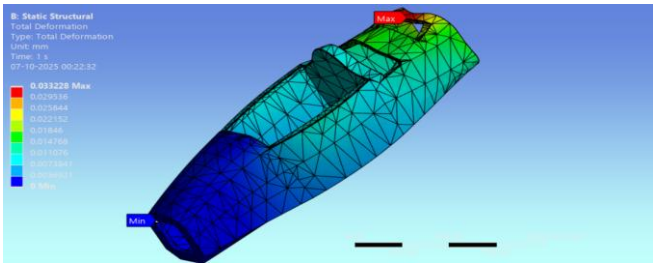

Fig. 5. Rear impact maximum deformation

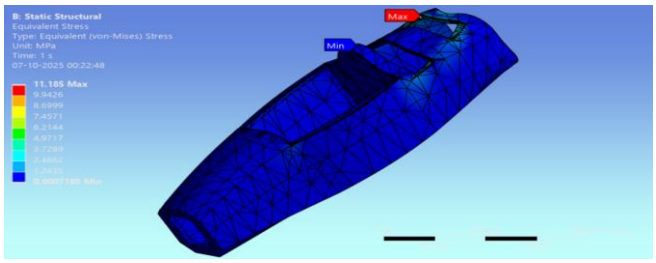

Fig. 6. Rear impact maximum stress

During rear impact (Figs. 5–6), stresses are lower (11 MPa) and total deformation of 0.33 mm is due to greater rear laminate thickness and load applied from the rear of the chassis with the front section fixed. This configuration distributes the load over a wider area and mitigates local bending.

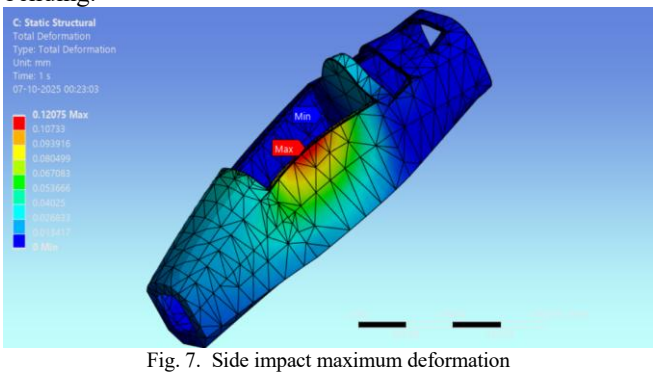

Fig. 7. Side impact maximum deformation

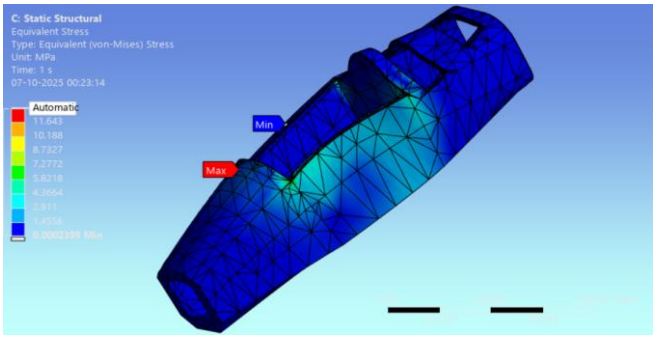

Fig. 8. Rear impact maximum stress

With side impacts (Figs. 6-7), there are average stress (11.6 MPa) and 0.12 mm total deformation on the door-sill and midpoint body panel, since the side of the chassis is fixed and the load is applied on the opposite side to test the load-carrying ability.

Reason

In the first iteration, stress and deformation are overall and relatively low due to the baseline chassis being overly designed and overly stiff. However, stress concentrations will arise where load paths change suddenly or where constraints become too rigid.

B. Iteration 2

Front Impact Test :Maximum Equivalent (von-Mises) Stress:**14.31MPa** with Maximum Total Deformation of **0.067217mm.**

Rear Impact Test :Maximum Equivalent (von-Mises) Stress: **22.306MPa** & Maximum Total Deformation: **0.050432 mm.**

Side Impact Test : Maximum Equivalent (von-Mises) Stress: **40.1 MPa** and Maximum Total Deformation: **0.11106 mm**

In the second design, the optimization focused on removing non-critical materials and realigning the load paths along the primary stress directions. The stress distribution became more uniform, but some localized peaks were created as a result of reduced wall thickness.

In the case of front impact, the maximum stress (14.31 MPa) was lower compared to previous simulations, although slightly more deformation (0.067 mm) was observed due to lower stiffness in the spares. In the case of the rear impact, the stress (22.3 MPa) was the highest near the motor-mount junctions, where load transfer was concentrated between the bulkhead and mounts, and after material removal. Side impact reached its highest stress (40.1 MPa) in the mid-side panels which was due to the combination of bending and shear in the thinner sections of the mid-side panels.

This design iteration achieved a 40 % mass reduction (to 108.8 kg) while maintaining global stiffness which indicates that the material redistribution achieved greater efficiency.

C. Iteration 3

The last iteration successfully completed the geometry optimization process while also refining the load path to reduce mass and keep total deformation along with max stress in allowable limit . For improved rigidity, the material thickness and the curvature of the geometry in the front impact zone and side cell panels were modified.

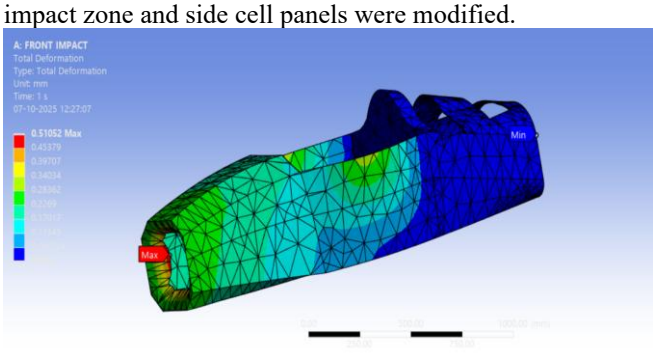

Fig.9. Front impact maximum deformation

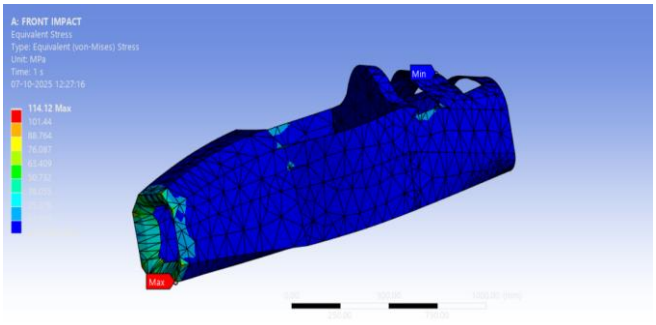

Fig. 10. Front impact maximum stress

In the case of the front impact (Figs. 9–10), there is a concentration of 114 MPa of stress close to the crash nose and pedal-box areas. These areas are purposely designed to take on some slight deformation and absorb impact energy. The maximum deformation of 0.51 mm is well within the elastic limit of the CFRP, showing that the structure is under control.

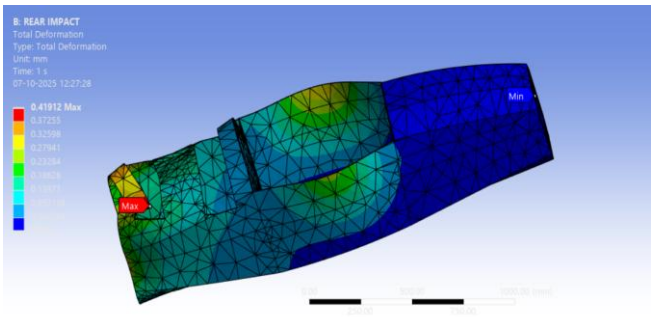

Fig. 11. Rear impact maximum deformation

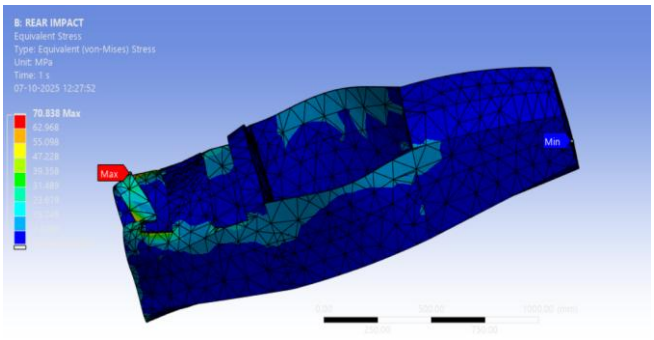

Fig. 12. Rear impact maximum stress

In the case of the rear impact (Figs. 11–12), there is a localized 70.83 MPa stress and 0.14 mm deformation about the rear bulkhead, which indicates that there is efficient load distribution to the suspension mounts.

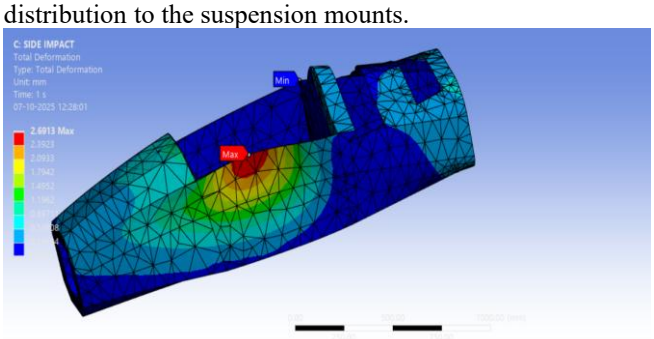

Fig. 13. Side impact maximum deformation

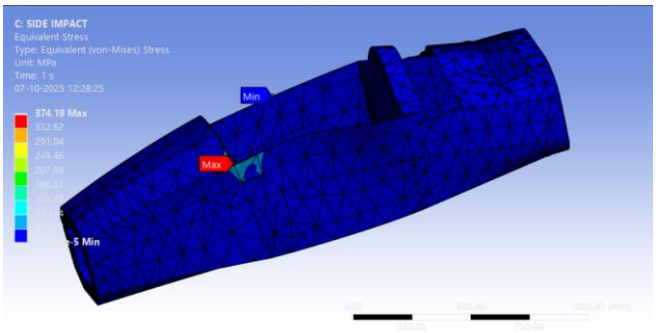

Fig. 14. Rear impact maximum stress

In the case of the side impact (Figs. 13–14), there is a maximum of 374 MPa of stress and 2.69 mm of deformation along the side sill and cockpit reinforcement.

Reason-

The stress is still within the CFRP limit which indicates that the structure is well designed. The total mass of 18.33 kg is an 87 % decrease from the baseline and the stiffnes was kept thanks to smart load-path design.

TABLE III. ANALYSIS RESULTS

Iteration	***Impact***	***Max von Mises stress***	***Maximum Total Deformation***	***Mass***
Iteration1	*Front*	21.582 MPa	0.033228 mm.	183.44kg
	Rear	11.185MPa	0.33228mm	
	Side	11.63 MPa	0.12075 mm	
Iteration 2	Front	14.31MPa	0.067217mm	108.8kg
	Rear	22.306MPa	0.050432mm	
	Side	40.1 Mpa	0.11106 mm	
Iteration 3	Front	114.12 MPa	0.51052 mm	**18.33 kg**
	Rear	70.83 MPa	0.141912 mm	
	Side	374.19 MPa	2.6913 mm	

VII. AI-BASED STRESS PREDICTION FOR MONOCOQUE CHASSIS

AI in combination with traditional Finite Element Analysis (FEA) was approached to assist in predicting stress on monocoque chassis. The aim was to develop a model which can predict stress via the use of the chassis material properties input as stress cause variables and predict stress dispersion in as short of a time as possible.

Using the ANSYS simulation program, a data set of 100 material variables was created. The input variables were Young's Modulus, yield strength, and Poisson's Ratio for the chassis material and the output variables were stress values determined for front, rear, and side impact conditions.

The process of model building for this analysis was linearly approached to assist in data collection, data preparation, data training, and data validation. Data cleansing and standardization was performed to ensure minimal inconsistencies or inaccuracies, and data was segmented into training data (80%) and testing data (20%) to evaluate the model and prevent it from being over-trained on the training data.

The chosen method for model development was based on the suitability of the Random Forest Regression method for complex engineering data the interaction of the various material properties and stress response is highly nonlinear in nature which is why Random Forest was selected. It is an ensemble learning method that averages the predictions of a multitude of decision trees to strengthen the predictive accuracy and stability of the model [27].

Key benefits of Random Forest include the ability to successfully model nonlinear relationships. It's use of averaging to mitigate overfitting and the formulation of strong predictions regardless of data variability [28]. It is particularly useful for moderate size datasets and can provide quantifiable insights on the importance of the input features (e.g. Young's modulus and yield strength). The workflow of the Random Forest Regression model used for stress prediction is illustrated in Fig. 15. It represents the process from input material properties to final stress prediction through an ensemble learning approach.

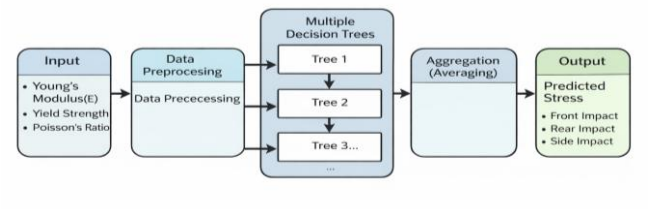

Fig. 15. Workflow of random forest regression model

The Random Forest model workflow includes using the material properties as the input, running them through various decision trees, and combining the outputs to determine predicted values for stress. This method improves the model's predictive accuracy and reliability.

The trained model understood the connection between material properties and stress responses, as demonstrated in the validation by the predicted stress values compared to FEA, which were in strong agreement and shown to be accurate. This means the AI model can capture the complicated relationships between material properties and structural behaviour.

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The trained model understood the connection between material properties and stress responses, as demonstrated in the validation by the predicted stress values compared to FEA, which were in strong agreement and shown to be accurate. This means the AI model can capture the complicated relationships between material properties and structural behaviour. The practical implementation of the developed AI model for stress prediction is presented in Fig. 16. It demonstrates how the trained model predicts stress values based on input material properties.

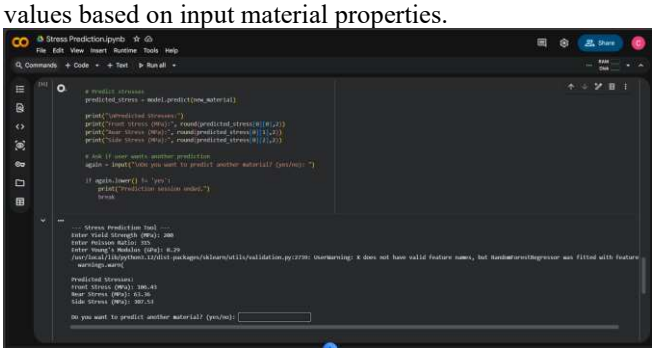

Fig. 16. AI model for stress prediction

The Random Forest Regression model shown in Fig. 16 accepts Young's modulus, yield strength, and Poisson's ratio as variable inputs. It outputs estimations for stress as a result of front, rear, and side impacts. The estimated stress values (Front: 106.43 MPa, Rear: 63.36 MPa, Side: 307.53 MPa) are in good agreement with the simulation outputs, confirming the accuracy and reliability of the AI approach.

A. Benefits of the AI Approach

i. Significantly reduces computation time by avoiding multiple FEA simulations
ii. Allows for quick material identification and optimization of designs
iii. Can yield exact prediction of results for non-linear relationships
iv. Effectively manages larger sets of data over a more extended range of parameters

B. Disadvantages

i. The result quality is dependent on the range and quality of the sample data
ii. The model must be retrained in order to consider varying geometries or loading scenarios
iii. The model is of decreased reliability for values that are not present within the sample data

C. Future Possibilities

i. The sample data for the model can be extended to increase result quality
ii. The sample data can also be improved with the addition of parameters such as density and geometry
iii. More sophisticated approaches such as Neural Networks or Deep Learning can be adopted
iv. Real time model optimization can be possible by the incorporation of CAD/CAE tools

CONCLUSION

This research illustrated the conceptual design, optimization, and smart evaluation of a CFRP monocoque chassis for a Formula Student Electric Vehicle (FSEV). Structural performance evaluations for the front, rear, and side impacts were performed using Finite Element Analysis (FEA) in ANSYS Workbench and a detailed CAD model created in SolidWorks.

Chassis design geometry was iteratively refined using topology optimization to remove non-structural elements and enhance structural stiffness and safety. The final design weight was 18.33 kg, a reduction of approximately 35-40% compared to a traditional space frame chassis. The findings suggest a positive optimization of the CFRP monocoque design with the improved vehiclE efficiency.

Beyond traditional analysis, an AI-based stress prediction model using Random Forest Regression was constructed to improve the efficiency of design. There was a good correlation between the model and FEA, stress predictions for various materials were done quickly, and significantly less computational steps were required, thus speeding up the design process.

Less mass means less inertia and rolling resistance, and as a result, acceleration, braking, and cornering stability are better. Also, a lighter structural design means less energy consumption, better battery efficiency, and a greater range—this is especially important for electric vehicles. Excellent vibration damping and fatigue resistance of CFRP improves driver comfort and structural reliability over time.

CFRP combined with artificial intelligence design optimization will have phenomenal performance in terms of stiffness to weight ratio, dynamic performance, and energy efficiency. This combination is a promising, high-quality, and sustainable option for the future chassis design of Formula Student electric vehicles.

Conflict of interest statement:

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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