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Development of Lightweight Chassis and Efficient Drivetrain for Formula Student Applications

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Abstract

The chassis and drivetrain of a Formula Student vehicle are designed, analyzed, and optimized in this research study with an emphasis on manufacturability, performance, and safety. The project emphasizes the use of advanced engineering tools such as SolidWorks for computer-aided design (CAD) and ANSYS for structural analysis to evaluate the chassis under various dynamic conditions. The primary objective is to ensure that the driver remains safe inside the cockpit while maintaining a lightweight, rigid, and ergonomically efficient structure that can house all necessary components.The study is divided into two major objectives. The first involves designing, manufacturing, and testing the Formula SAE race car chassis by considering critical factors such as vehicle dynamics, torsional rigidity, component packaging, ergonomics, and overall driver safety. Special focus is given to optimizing the chassis for structural strength while minimizing unnecessary weight. The second objective emphasizes the design and optimization of the drivetrain, including chain, sprockets, axles, and differential systems, to achieve maximum efficiency and smooth power transmission. References from SAE research papers and standard textbooks were extensively utilized to validate calculations and improve design accuracy The CAD models were developed in SolidWorks 2020–21, followed by 2D and 3D structural simulations in ANSYS 2021 to evaluate the chassis against frontal, side, and torsional loads. Fabrication was carried out in-house using TIG and arc welding, supported by jigs and fixtures to ensure accuracy. The high strength-to-weight ratio, weldability, and availability of AISI 4130 chromium-molybdenum alloy steel made it the material of choice for the chassis.The final outcomes demonstrate that the optimized chassis and drivetrain not only meet competition rulebook standards but also enhance driver safety, performance reliability, and structural durability. These results serve as a valuable contribution to the ongoing development of cost-effective and efficient Formula Student vehicles.

Keywords: Chassis design, drivetrain optimization, structural analysis, AISI 4130 steel, formula student vehicle

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INTRODUCTION

Students must design, construct, and compete in a formula-style race car as part of the SAE Formula Student competition, a prestigious worldwide engineering challenge. Among the critical subsystems of such vehicles, the chassis and drivetrain play central roles in determining safety, handling, and overall performance. The chassis functions as the skeletal structure of the car, supporting loads, resisting stresses, and providing mounting points for other systems [1]. In the meantime, the drivetrain makes sure that power is transferred smoothly from the engine to the wheels, which has a direct impact on speed, acceleration, and dependability.[2].

This paper focuses on designing and optimizing both the chassis and drivetrain of a Formula Student vehicle, while adhering to safety and performance standards set by the rulebook [3]. Using CAD and CAE tools, the study investigates torsional stiffness, crashworthiness, and drivetrain efficiency, followed by fabrication and validation.

Nomenclature

Z_p No. of teeth of pinion
Z_g No. of teeth of gear
M module
b face width
P(kw) power of engine
N_P(RPM) Speed of pinion
γ pitch angle
α pressure
M_T module estimation
R_M radius of pinion
Q ratio factor
D_P diameter of pinion
K material constant
D_G diameter of gear
C_S service factor
Y_P Lewi's form factor (pinion)
P_d dynamic load
A_0 cone distance
V Pitch line velocity
e Error according to class
C Deformation factor

LITERATURE REVIEW

The role of CAD and CAE integration in vehicle design has been highlighted across numerous studies. Simulation-based methods reduce costs, enhance safety, and allow engineers to refine prototypes virtually. Seward demonstrated how CAD-assisted simulation improves early design decision-making. The Efficycle and Supra SAE rulebooks [4] provide essential guidelines for structural strength, driver protection, and component packaging.

Past works demonstrate the relevance of simulation-driven optimization. Grover et al. used CAE to evaluate lithium-ion battery systems, while Jindal et al. validated BAJA chassis torsional stresses using gyroscopic sensors. Similarly, Saini and Rana highlighted CAE's role in Formula SAE suspension analysis. Upadhyaya et al. optimized brake calipers using FEA, while Sharma et al. applied simulation methods to Efficycle chassis.

Collectively, literature confirms that CAE not only reduces prototyping costs but also ensures compliance with safety standards, which this study builds upon [5].

Chassis

The primary support structure of the car is the chassis, sometimes referred to as the "Frame." It withstands all of the stresses placed on the vehicle in both static and dynamic situations. It's like a living creature's skeleton within a car [6].

The French language is where the word "chassis" first appeared. Every vehicle, be it a car, truck, three-wheeler, or two-wheeler, has a chassis or frame [7]. Its shape clearly differs depending on the type of vehicle, though. The following are the functions of the chassis. It:

- Provides room and a mounting area for different vehicle components;
- Supports or bears the weight of the vehicle body.
- Supports the weight of various systems of the vehicle such as engine, transmission etc.
- Supports a load of passengers as well as the luggage.
- Withstands the stresses arising due to bad road conditions.
- Withstands stresses during braking and acceleration of the vehicle.

According to our rulebook, our chassis is divided into three parts; FRONT BULKHEAD, COCKPIT and REAR.

Drivetrain and its Components

A vehicle's drivetrain is a system that distributes power throughout it and uses engine power to turn the wheels and move it. Transferring power from the engine to the driving wheels, which use the mechanical force to spin the axle, is the responsibility of the drivetrain [8]. In contrast, the engine, drivetrain, and/or motor or motors are considered to be a part of the powertrain. Through Derek Seward, we learnt about the drivetrain and transmission system of a formula-3 vehicle. The rulebook gave us the rules and regulations for designing and manufacturing our drivetrain system [9].

Chain and Sprocket

Usually connected by a chain or belt, a sprocket is a wheel with teeth around the rim that transfers power and rotation from one device to another. Bicycles, motorbikes, and other mechanical systems frequently employ sprockets to transfer motion and power between various parts. The teeth of a sprocket engage with the links of a chain or belt to enable a smooth and efficient transfer of power [10-11]. Sprockets come in a variety of sizes and styles and can be made from a variety of materials, including steel and aluminum.

Differential

In order to allow the inner wheel to rotate more slowly than the outer wheel when cornering, the differential transfers power from the gearbox to the driven wheels [12]. The engine power and torque are transmitted and divided into two flows between the wheels on the same axle by the differential. If one of the wheels has poor road grip, this reduces tire wear by allowing the wheels to rotate at separate speeds, increasing stability and preventing sliding [13-15]. We were able to comprehend the differential gear calculations thanks to the book V.B. Bhandari.

Axles

The drive axle's job is to transfer power from the engine to the wheel. One end of the driving axle is connected to the wheel, and the other end is connected to the differential [16]. Torsional and bending stresses are applied to the drive axle of the majority of automobiles on the road. Splines on both ends of the components transfer torque to and from the half-shaft. The books N.K. Giri and V.B. Bhandari helped us to understand the concepts and calculations related to axles.

Types of Differentials

Open differential – The open differential, one of the more popular kinds of differentials, divides engine torque in half and permits the wheels to spin at different speeds. It is used in the majority of family sedans and budget vehicles. A locking differential, sometimes referred to as a welded differential, joins the wheels to ensure that they travel at the same pace [17-18]. It was a little harder to turn because of this. This kind of differential is seen in the majority of full-sized trucks.

Sports cars often use limited-slip differentials, which by default function similarly to an open differential. To increase grip and control on the road, a wheel that has lost traction switches to function as a locking differential. Torque-vectoring differential: The torque-vectoring differential can adjust the amount of torque applied to each wheel by adding more gear trains [19-21].

METHODOLOGY

The following flowchart of Figure 1-7 depicts the flow of our project work:

Figure 1. Prototype.

Figure 2. Data collection.

		Bending strength	**Bending stiffness**
	Unit	***Nm***	***Nm^4***
Material-1	AISI 1018		
Cross Section	B = 21.4 T = 2 A = 25.4	291.331	2078,031
Material-2	AISI 1018		
Cross Section	A = 25.4 B = 23.4 T = 1	164.144	1170.824
Material-3	AISI 1018		
Cross Section	A = 28 T = 2 B = 24	211.073	2845.154
Material-4	AISI 4130		
Cross section	A = 25.4 B = 21.4 T = 2	353.368	1960.18
Material-5	AISI 4130		
Cross section	B = 23.4 A = 25.1 T = 1	97.812	1085.154
Material-6	AISI 4130		
Cross section	A = 28 B = 24 T = 2	431.234	2636.972

Figure 3. Calculations.

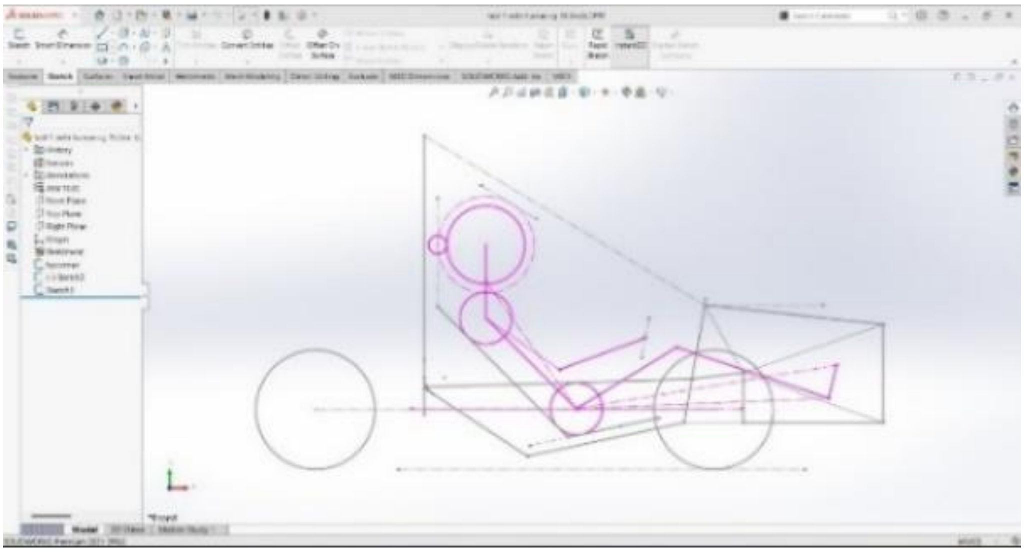


Figure 4. Cad modelling.

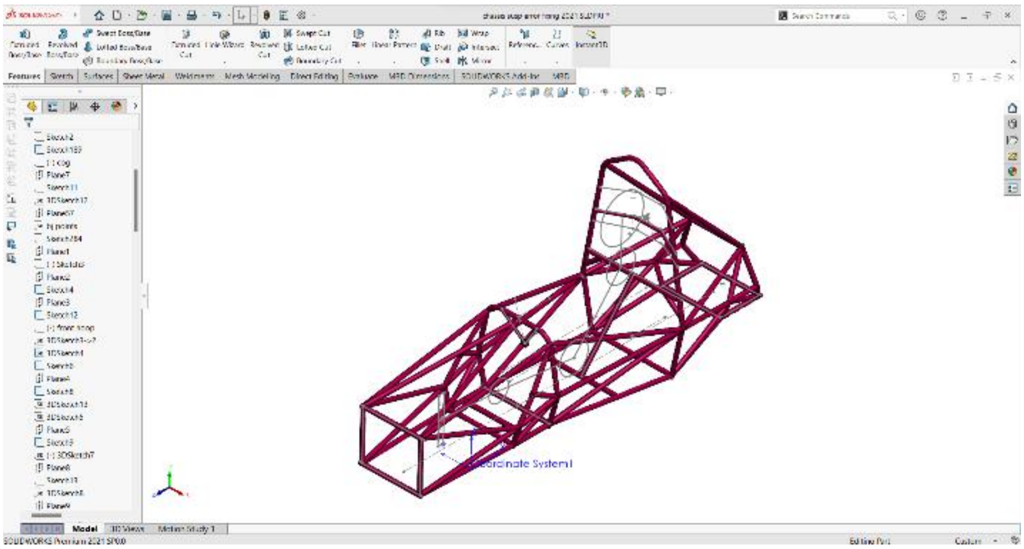


Figure 5. Final cad modelling.

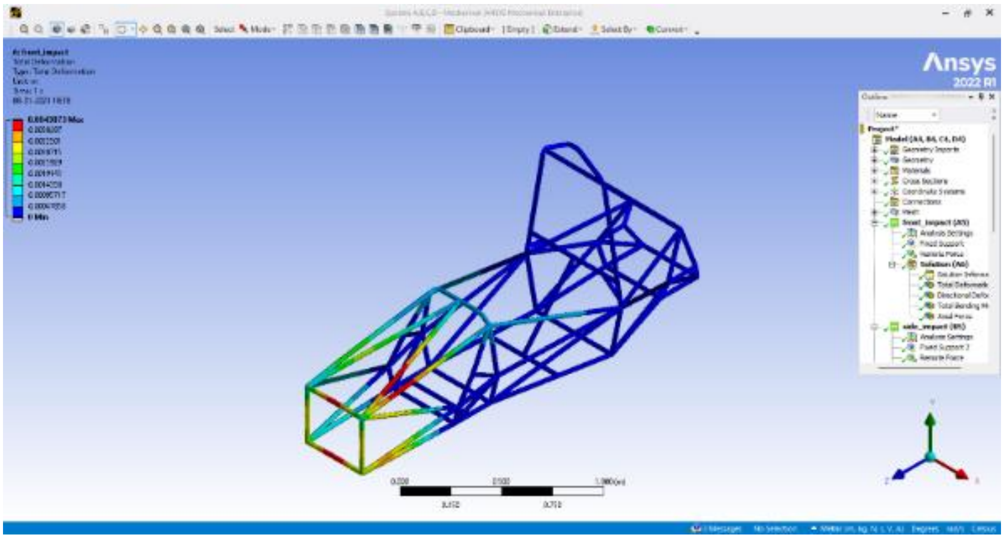


Figure 6. Analysis.

Figure 7. Fabrication.

NUMERICAL ANALYSIS

Chassis

Torsional Stiffness Calculation:
Maximum Deflection front (Z1) = 9.9mm = 0.0099m (from FEA)
Maximum Deflection rear (Z2) = 7.6mm = 0.0076m (from FEA)
Track width (L) = 0.9915m

Cornering force upward on wheel for front (F1) = 1828.5N
Cornering force upward on wheel for rear (F2) = 1598.59N
Torsional stiffness = C

For Front:
T1 = torque = F1 × L= 1812.95775 Nm (1)
Ɵ1 = Angle of deflection = arctan (Z1 ÷L) = 0.572 deg (2)
C1 = T1 ÷ Ɵ1= 3169.5Nm/deg (3)

For Rear:
T2 = torque = F2 × L = 1585.001985 Nm
Ɵ2 = Angle of deflection = arctan (Z2 ÷L) = 0.439 deg
C2 = T2 ÷ Ɵ2 = 3610.48Nm/deg
For torsional stiffness of chassis = (C1＋C2) ÷2 (4)
So, torsional stiffness of chassis is 3390 Nm/deg
Minimum Fos = 2.73

Impact Force Calculation

Impact force (F) = Mass of vehicle with driver (M) × Acceleration of vehicle (A) (5)
F = M × [change in velocity (Δv) ÷ change in time (Δt)] (6)
M = 350kg (assume)

For frontal impact:
U = 0 m/s V = 120 km/h = 33.33 m/s Δt =0.2 sec
F = 350 × [(33.33 − 0) ÷ 0.2] = 58327.5N

For side impact:
1) U = 0 m/s V = 100 km/h = 27.77 m/s Δt =0.2 sec
F = 350 × [(27.77 − 0) ÷ 0.2] = 48597.5N
2) U = 0 m/s V = 60 km/h = 16.66 m/s Δt =0.2 sec
F = 350 × [(16.66 - 0) ÷ 0.2] = 29115N

MATERIAL SELECTION
MATERIAL -1 (AISI4130)
FOR AISI 1018 WITH CARBON % 0.18
Outer Diameter -25.4mm and Thickness – 2mm

BENDING STRENGTH
M=Sy×I÷c (7)
C=25.4÷2=12.7mm
SY=365MPa
I=π ((O.D)4__ (I. D)4) ÷64 (8)
=π ((25.4)4__ (21.4)4) ÷64=10316.74mm4
M= (365×106 × 10316.74×10-12 ×2) ÷25.4 ×10-3
=291.331Nm

BENDING STIFFNESS:
E=205GPa
I=10316.74mm4
EI=2078.031Nm4 (9)
Outer Diameter-25.4mm and Thickness-1.6mm

BENDING STRENGTH
M=Sy×I÷c
C=25.4÷1.6=15.875mm
SY=365MPa
I=π ((O.D)4__ (I. D)4) ÷64
=π ((25.4)4__ (22.2)4) ÷64=8504.50mm4
M= (365×106 × 8504.50×10-12 x1.6)÷25.4 ×10-3
=195.536Nm

BENDING STIFFNESS
E=205GPa
I=8504.50mm4
EI=1743.42Nm4
MATERIAL -2 (AISI 1018)
FOR AISI 4130
OUTER DIAMETER -25.4 and INNER DIAMETER-21.4MM Thickness –2mm

BENDING STRENGTH
M=Sy×I÷c
C=25.4÷2=12.7mm
SY=435MPa
I=π ((O.D)4__ (I. D)4) ÷64
I=10316.74mm4
M= (435 × 106 ×10316.74×10-12×2) ÷ 25.4×10-3=353.368Nm

BENDING STIFFNESS

E=190GPa
I=10316.74mm4
EI=1960.18Nm4

Drivetrain

The torque and speed are calculated for each gear by considering the primary driver ratio (Gear ratios in stock engine gearbox from the manufacturer) as well as secondary drive ratio (chain gear reduction) (Table 1-4).

Primary Drive ratio =30:80 = 2.66:1
Secondary Drive ratio = 48:15 = 3.2:1
Overall gear ratio = Primary drive ratio × Secondary drive ratio x Individual gear ratio (10)

The Torque values at each individual gears can be obtained by Torque = Maximum engine torque × Overall gear ratio (11)

The Rotation per minute can be calculated at each gear by the formula
RPM=Engine rpm/Overall ratio (12)
Radius of wheel = 9 inch =0.2286m
Force = Torque/ Radius of wheel (13)

Force required overcoming rolling resistance could be calculated as follows:
Rolling resistance, Fr = fmg (14)

Where f =co-efficient of rolling resistance = 0.015
Acceleration due to gravity, g = 9.81m⁄s^2
Mass of vehicle, m = 300kg
Fr = 0.015×300×9.81
Fr = 44.145N
Force available = Force delivered – Rolling resistance (15)
Acceleration = Force available/weight
Speed of the vehicle at each gear is, Speed = RPS×2πr×3.6 (16)

Table 1. Gear ratio.

Gears	Individual ratios	Overall gear ratio	Engine torque
1st	2.6666	22.6980992	26
2nd	1.8571	15.8076352	30.5
3rd	1.4211	12.096432	33.02
4th	1.1428	9.725136	26
5th	0.9565	8.141728	25
6th	0.84	7.15008	25

Table 2. Final RPM Calculation.

Engine RPM	Overall gear ratio	Final RPM	RPS
4000	22.6980992	176.2262	2.935922
6000	15.8076352	379.5634	6.323526
8000	12.096432	661.3536	11.01815
10000	9.725136	1028.012	17.12668
10000	8.141728	1228.24	20.46249
10000	7.15008	1398.586	23.30044

Table 3. Final acceleration calculation.

Gears	Final torque	Wheel radius (m)	Force delivered (N)	Acceleration
1	590.1505792	0.2286	2581.586	8.458137
2	482.1328736	0.2286	2109.068	6.883076
3	399.4232337	0.2286	1747.258	5.677044
4	252.9153536	0.2286	1106.366	3.5407388
5	203.5432	0.2286	890.3902	2.820817
6	178.752	0.2286	781.9423	2.459324

Table 4. Speed calculation.

Gears	RPS	Speed (km/h)
1	2.935929	15.17343
2	6.323526	32.68118
3	11.01815	56.94389
4	17.12668	88.51391
5	20.46249	105.754
6	223.30044	120.4211

Differential

Circumference of wheel = $2\times\pi\times R = 2\times3.14\times0.2286 = 1.43$m (17)

Circumference of outer wheel trajectory = $3.14\times D2 = 3.14\times5=15.7$m (18)

Circumference of inner wheel trajectory = $3.14\times D1 = 3.14\times2.62 = 8.2$m (19)

Ratio (C/A) (D) = 8.2/1.43= 5.73 (20)

Hence, Inner wheels needs 5.73 rotation to complete one revolution of circular trajectory.

Ratio (B/A) (E) = 15.7/1.43 = 10.98 (21)

Hence, Outer wheels needs 10.98 rotation to complete one revolution of circular trajectory.

Ratio(E/D) = 10.98/5.73 = 1.92 (22)

Hence outer wheel rotates 1.92 times faster than inner wheel.

Reduction between spider gears and side gears = 1.92

1.20 (Considering available module)

$Z_P = 14$ $Z_G = 28$

Pitch angle: Alpha (α) = $\tan^{-1}(Z_P/Z_G) = \tan^{-1}(14/28) = 26.56$degree (23)

Bending strength = Sut/3 = 1100/3 = 366N/mm^2 (24)

Lewi's form factor (Yp) = 0.487-2.87/14 = 0.282 (25)

Power = Torque × (R.P.M)/5252 = 590.15×176.23/5252 = 14.76kw (26)

Speed of pinion (RPM) Np = 1398.586 Rpm

MODULE ESTIMATION

MT=Torque Transmissible

MT= (60*Power)/(2*3.14*Np) 10^6 (27)

MT=100872.037Nmm

TANGENTIAL LOAD (PT): PT = 2×MT/DP

PT = 2×100872.037

PT = 8762.28m

we have

b= 10 m or b = A0 /3 (whichever is smaller)

b = face width, A0 =Pitch cone distance

BEAM STRENGTH(Sb)

Sb=m × b× Sb× Yp [1− (b/Ao) (28)

Sb=m × 14m × 366 × 0.2 × [2/3]

Sb=340m^2

PITCH LINE VELOCITY(V)

V=π×D_p ×N_p ÷60×10^3 (29)

V=3.14×56×1398÷60×10^3

V= 3.713m/sec

DYNAMIC LOAD (P_d)

C=11400N/mm^2

P_d=21×v×(c×e×b+Pt) ÷21v+(c×e×b+Pt)^(1/2) (30)

P_d=21×2.926× (11400×0.0125×17+5043.60) ÷21×2.926+ (11400×0.0125×17+5043.60)^(1/2)

P_d=2390.63N

Effective load (P_eff):

P_eff=C_s. P_t + P_d (31)

= 1×2009.07 + 2390.63

= 4399.708 N

F.O.S = S_b/P_eff (32)

= 5445.75/ 4399.708

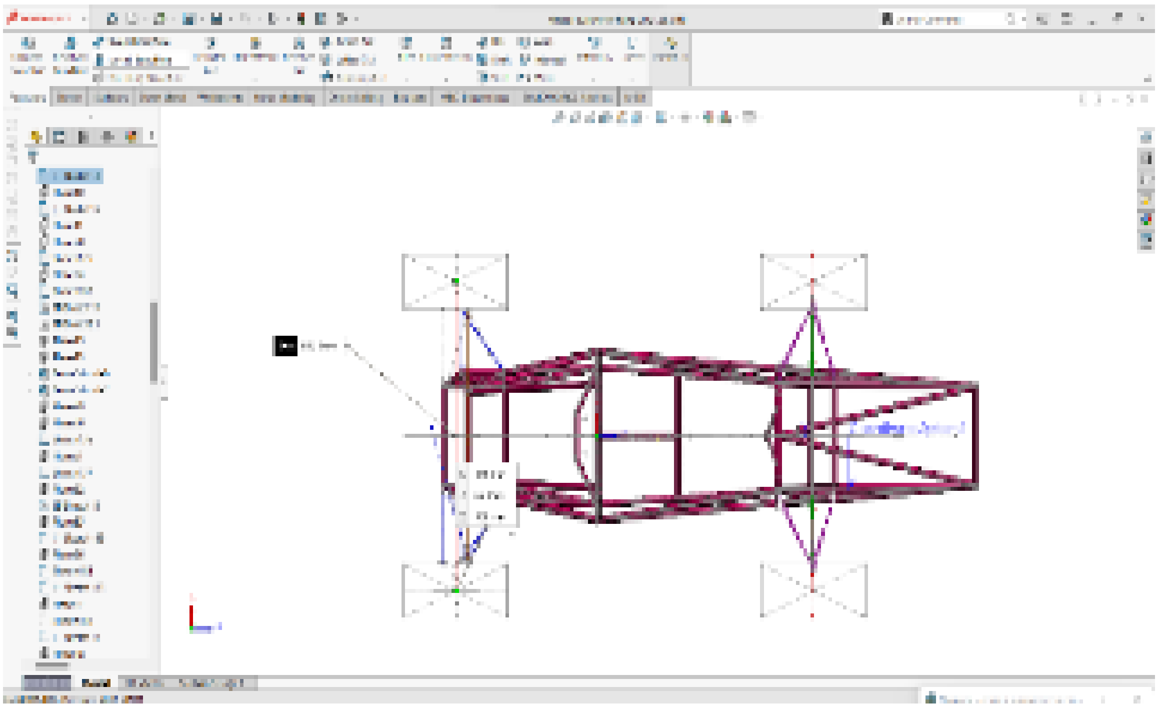
= 1.02

CAD MODEL AND CAE ANALYSIS

There are various Figures which show the mechanism of the workflow.

Chassis

Figure 8-12 shows the various views of chassis CAD model, front impact, side impact, rear impact (a) axial (b) directional, torsional (a) procedure (b) directional respectively.



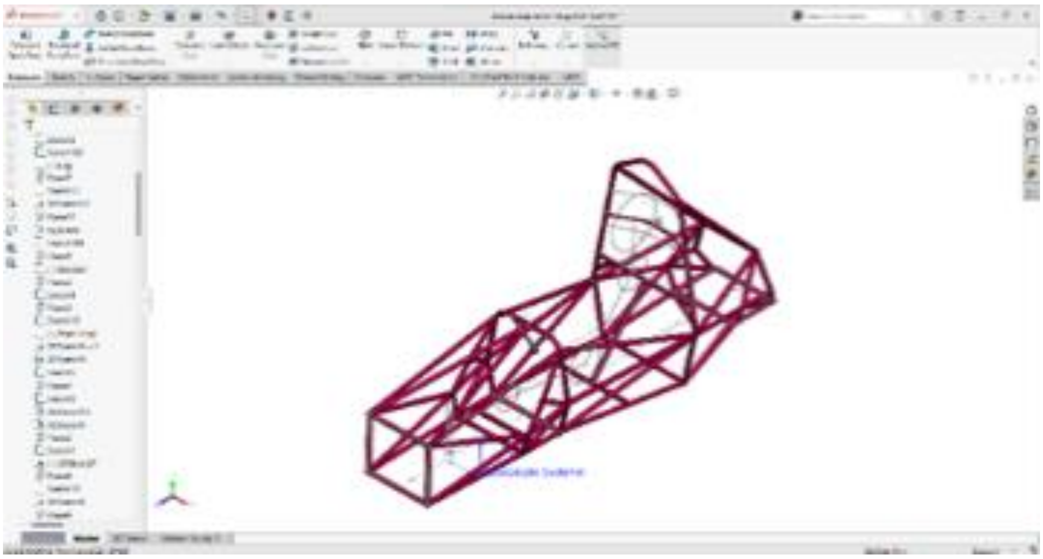
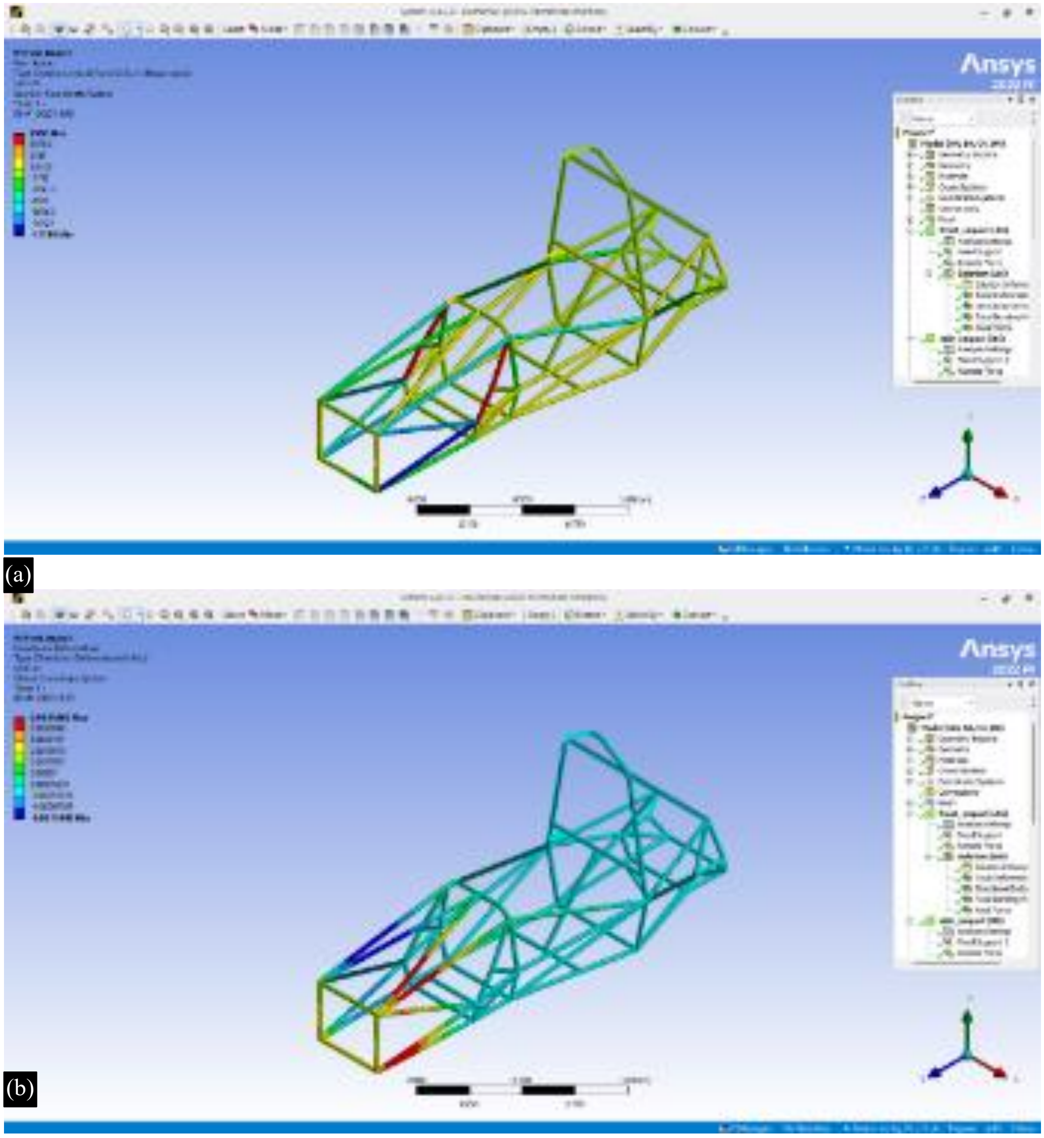


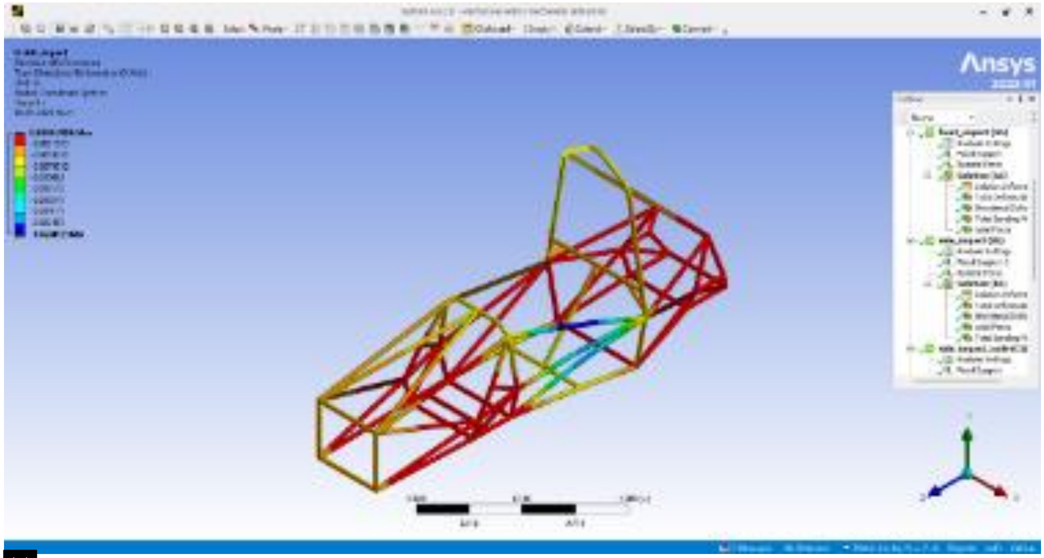
Figure 8. Various views of chassis cad model.



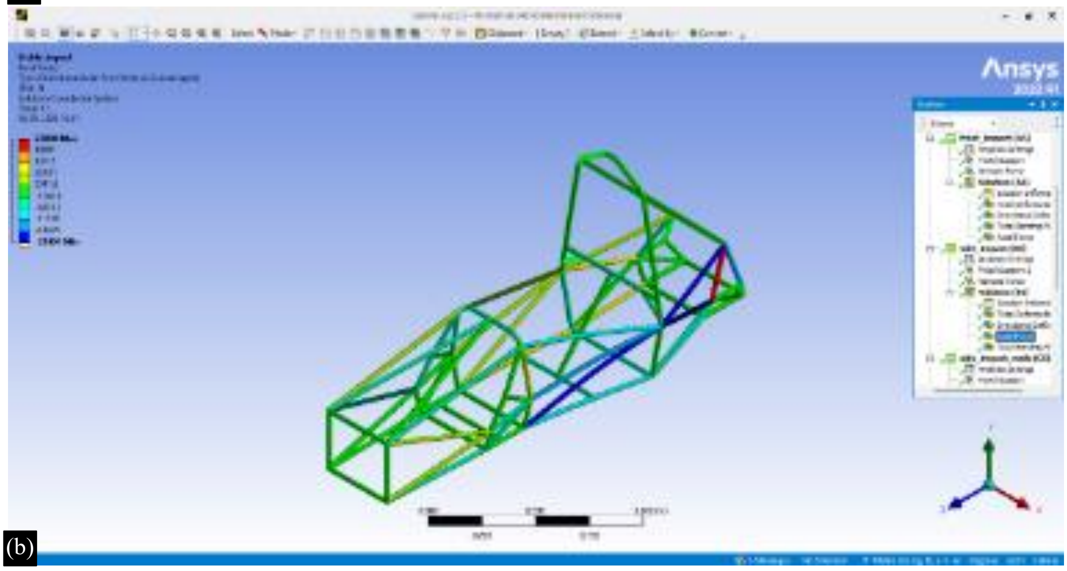
(a)

(b)

Figure 9. Front impact a) Axial b) Directional.

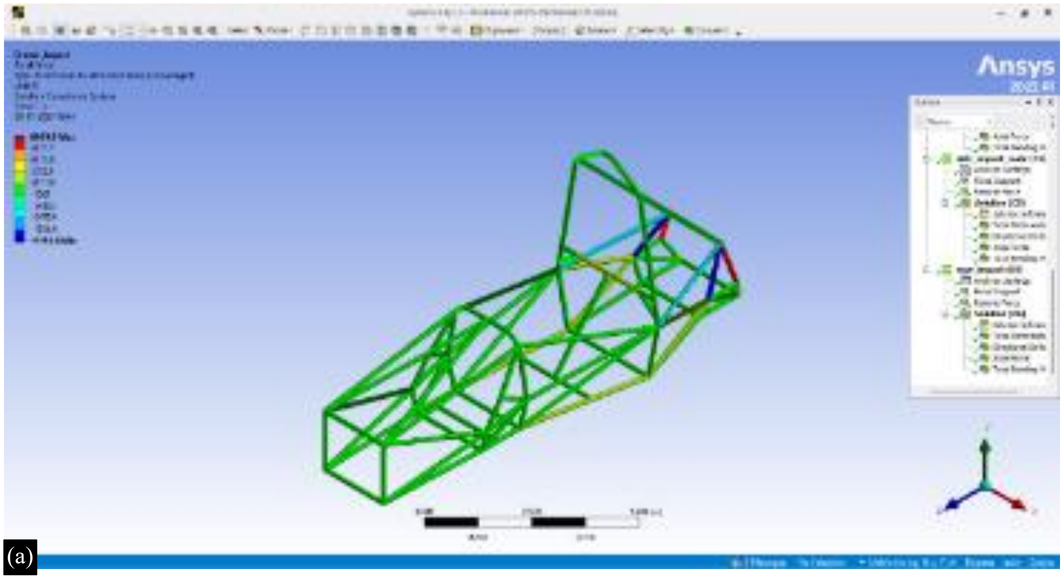


(a)



(b)

Figure 10. Side impact a) Axial b) Directional.



(a)

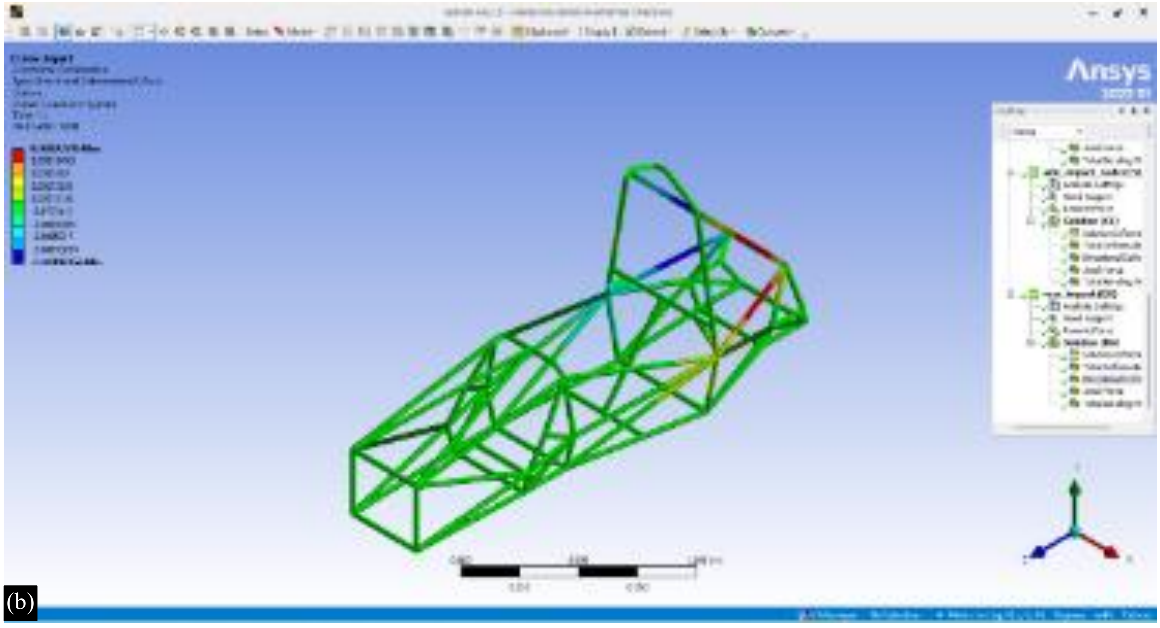


Figure 11. Rear impact a) Axial b) Directional.

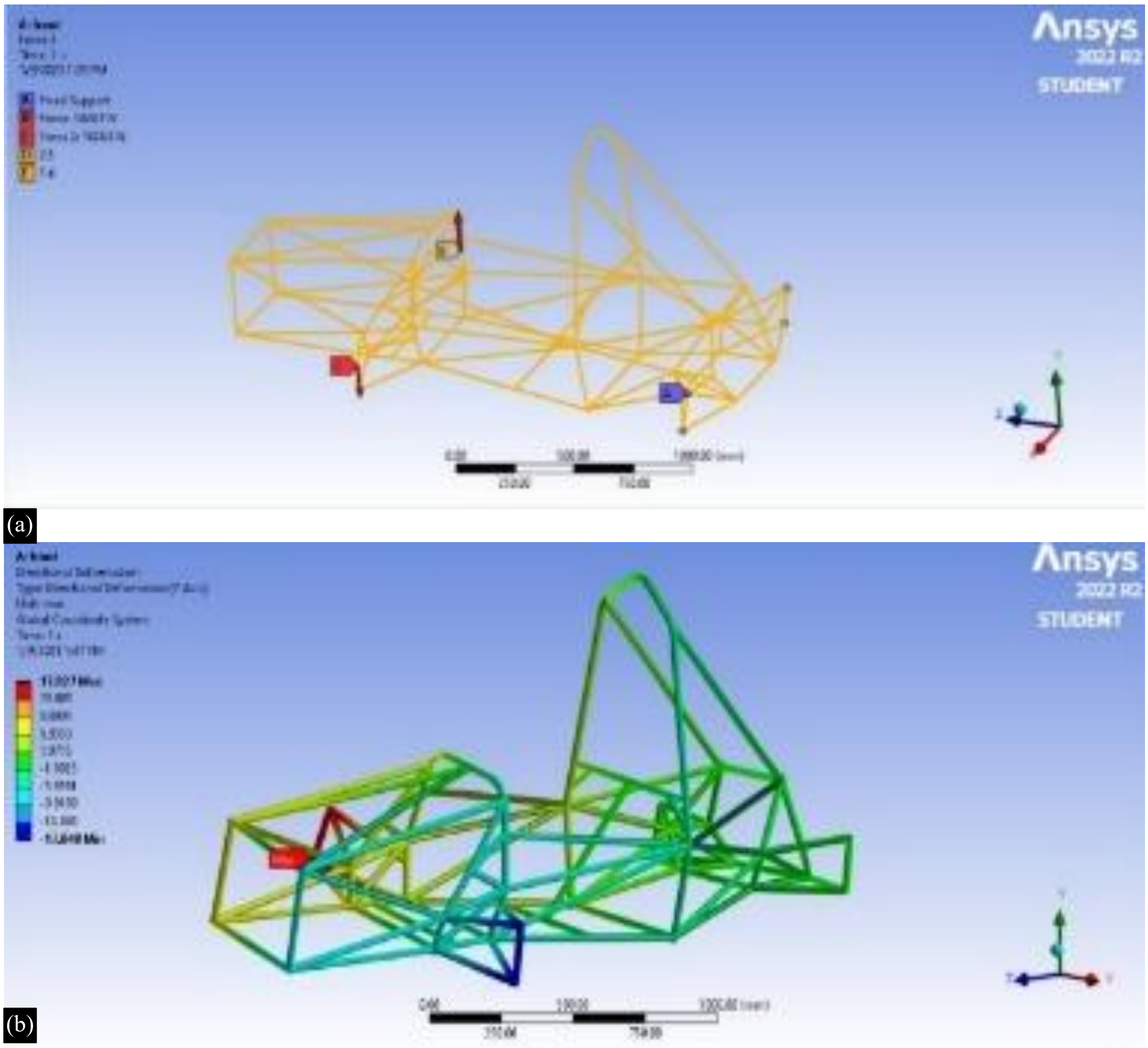


Figure 12. Torsional a) Procedure b) Directional.

Drivetrain

Figure 13-16 shows the differential, assembly, sprocket, gears (a) mesh (b) result respectively.

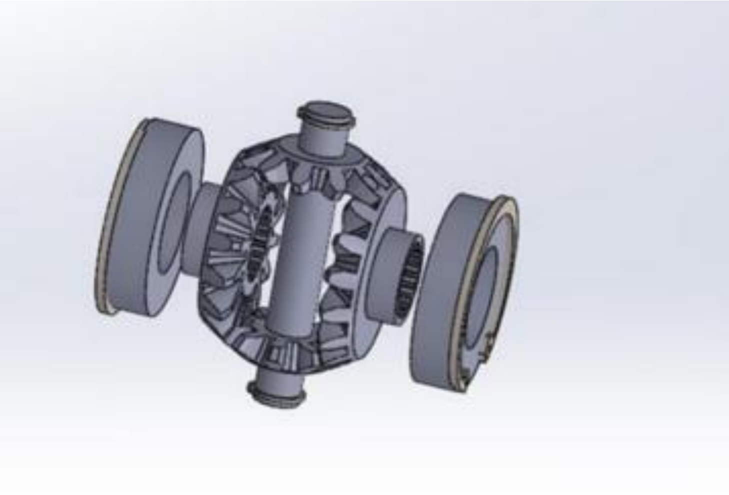


Figure 13. Differential.

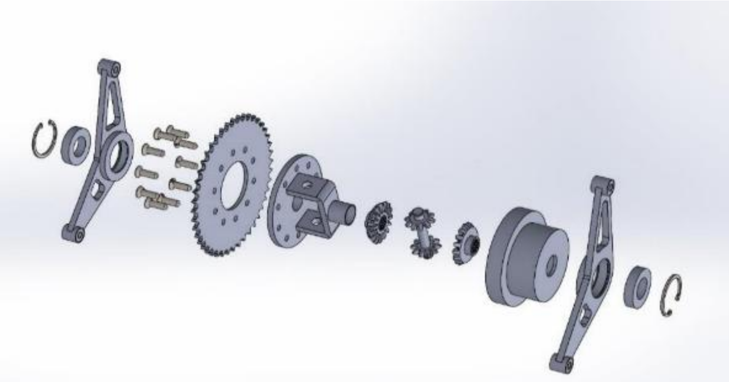


Figure 14. Assembly.

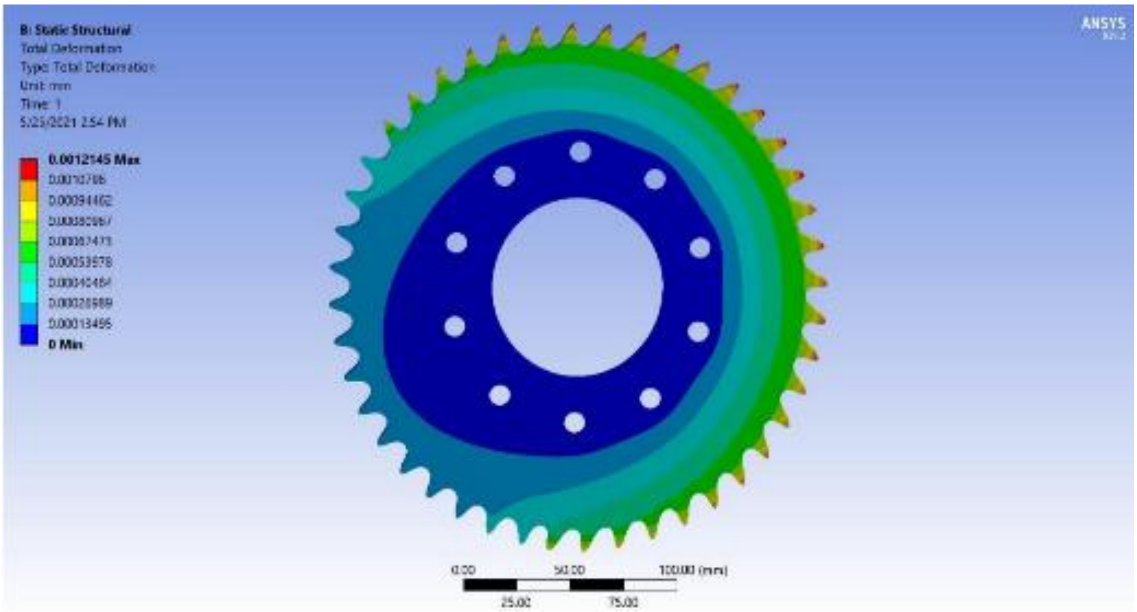


Figure 15. Sprocket.

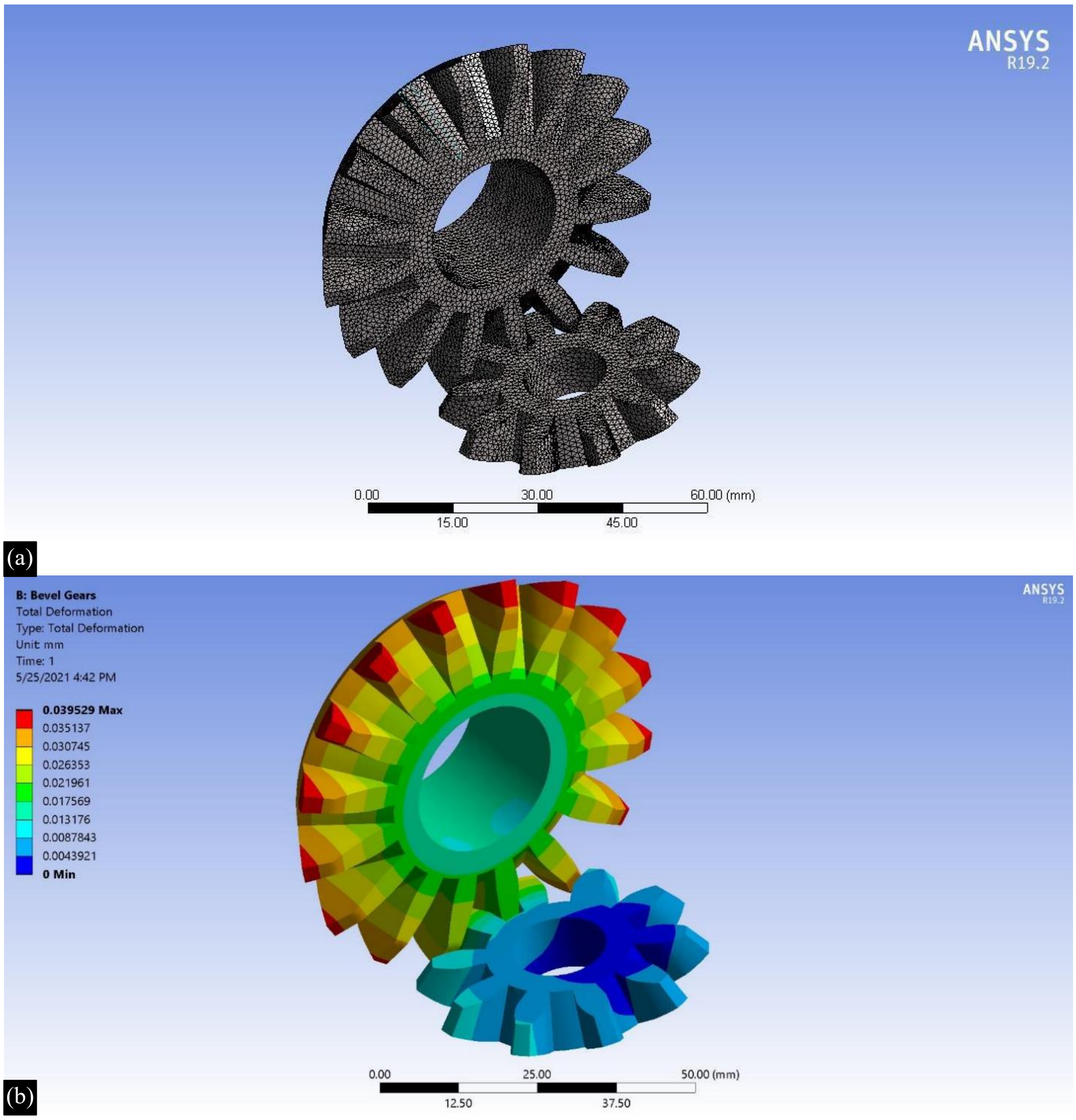


Figure 16. Gears a) Mesh b) Result.

RESULT

The Figure 17 shows the manufactured chassis and drivetrain which shows a fully completed vehicle.

Figure 17. Manufactured chassis and drivetrain.

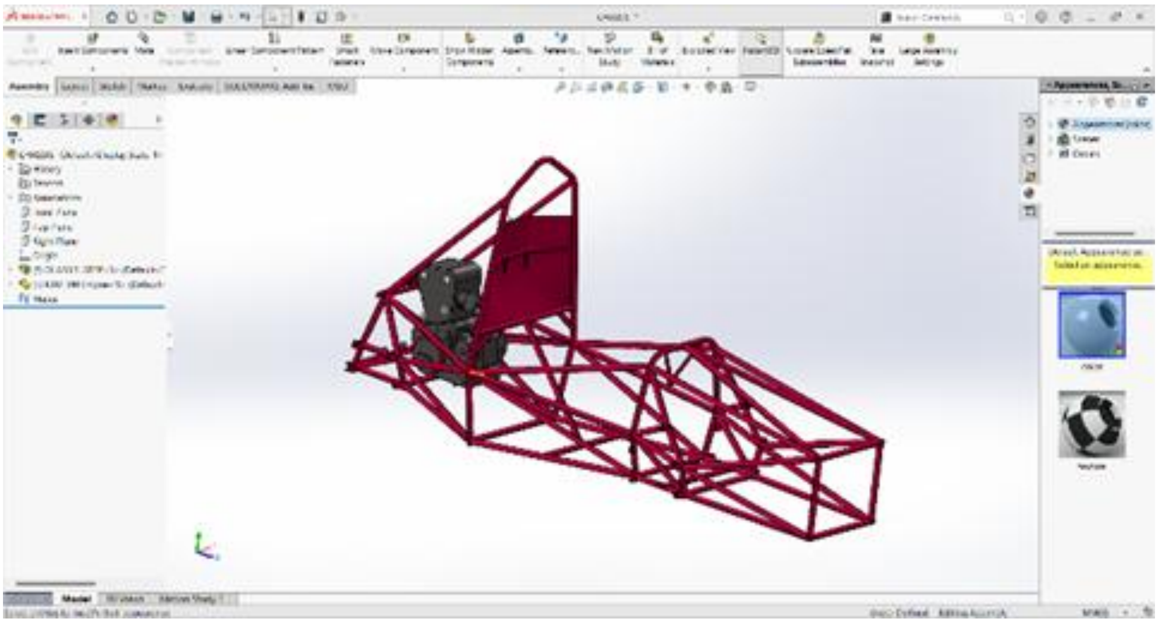


Figure 18. Final cad model.

Chassis

The final cad model of chassis was designed after incorporating the results from analysis. Then the chassis was manufactured from material AISI-4130 (Figure 18).

Drivetrain

The final cad model of differential was designed after incorporating the results from analysis. Then the differential was manufactured from following material:

Bevel Gears= EN24
Casing= Aluminum 6061 T6
Axles= En8
Mountings= Mild steel (8mm)

The following data was also found after the final calculations:

The maximum speed is 120.42km/h
The maximum acceleration will be 8.46 m⁄s^2

CONCLUSION

This study successfully demonstrates the design and optimization of the chassis and drivetrain of a Formula Student vehicle using CAD and CAE tools. The integration of SolidWorks modeling with ANSYS analysis enabled accurate evaluation of structural strength, torsional rigidity, and crashworthiness. AISI 4130 steel proved to be the most suitable material due to its strength-to-weight ratio and weldability. The fabricated prototype met all competition safety and performance requirements, ensuring driver protection while maintaining efficiency. Future work may involve fatigue analysis and dynamic load testing.

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