Finite Element Analysis of a Mono Composite Leaf Spring of Lightweight Vehicles for Reducing Fuel Consumption

Bonsa Tamiru Alemu

A Thesis submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical and Materials Engineering.

Presented in Partial Fulfillment of the Requirements for the Degree of Master's in Automotive Engineering.

Office of Graduate Studies

Adama Science and Technology University

June, 2024

Adama, Ethiopia

Finite Element Analysis of a Mono Composite Leaf Spring of Lightweight Vehicles for Reducing Fuel Consumption

Bonsa Tamiru Alemu

Advisor: Getachew Alemayehu (PhD)

A Thesis submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical and Materials Engineering.

Presented in Partial Fulfillment of the Requirements for the Degree of Master's in Automotive Engineering.

Office of Graduate Studies

Adama Science and Technology University

June, 2024

Adama, Ethiopia

DECLARATION

I hereby declare that this Master Thesis entitled "***Finite Element Analysis of a Mono Composite Leaf Spring of Lightweight Vehicles for Reducing Fuel Consumption***" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Bonsa Tamiru Alemu	__________________	June, 2024
Name of the student	Signature	Date

RECOMMENDATION

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "***Finite Element Analysis of a Mono Composite Leaf Spring of Lightweight Vehicles for Reducing Fuel Consumption***" prepared under my/our guidance by Bonsa Tamiru Alemu submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Automotive Engineering. Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

______________________	______________________	______________
Major Advisor	Signature	Date
______________________	______________________	______________
Co-advisor	Signature	Date

APPROVAL

I/we, the advisors of the thesis entitled "***Finite Element Analysis of a Mono Composite Leaf Spring of Lightweight Vehicles for Reducing Fuel Consumption***" and developed by Bonsa Tamiru Alemu hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

____________________________	________________________	________________
Major Advisor	Signature	Date
____________________________	________________________	________________
Co-advisor	Signature	Date

APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the thesis by Bonsa Tamiru Alemu have read and evaluated the thesis entitled "***Finite Element Analysis of a Mono Composite Leaf Spring of Lightweight Vehicles for Reducing Fuel Consumption***" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Automotive Engineering.

Chairperson	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

ACKNOWLEDGEMENT

I would like to express my gratitude to the almighty God for giving me time, strength and health during the preparation of this thesis. My deepest gratitude goes to my Advisor, Getachew Alemayehu (PhD), for his help, advice and guidance that gave me direction and made me put intelligent effort on this thesis work. My special thanks go to my family and my friends, for their unwavering support and encouragement throughout my thesis. Then, I would like to express my sincere gratitude and appreciation to my classmates.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

3D	-	*Three Dimensional*
AFRP	-	*Aramid Fiber Reinforced Polymers*
b	-	*Width of the beam*
BFRP	-	*Bassalt Fiber Reinforced Polymers*
CAD	-	*Computer Aided Design*
CFRP	-	*Carbon Fiber Reinforced Polymers*
E	-	*Young's modulus of the leaf spring material*
FEM	-	*Finite Element Method*
FRP	-	*Fiber glass-reinforced plastic*
F_S	-	*Safety Factor*
g	-	*Acceleration due to Gravity*
GFRP	-	*Glass Fiber Reinforced Polymers*
GHG	-	*Green House Gas*
I	-	*Moment of Inertia of the beam*
L	-	*Length of the beam*
L_{BF}	-	*Length of Bassalt Fiber leaf spring*
L_{CF}	-	*Length of CFRP leaf spring*
L_{EG}	-	*Length of E – Glass leaf spring*
L_{SS}	-	*Length of structural steel leaf spring*
L_T	-	*Length of Technora H leaf spring*
M	-	*Maximum Bending Moment*
MCLS	-	*Mono Composite Leaf Springs*
M_t	-	*Total mass of the Vehicle*
PMC	-	*Polymer Matrix Composite*
t	-	*Thickness of the beam*
t_{BF}	-	*Thickness of Bassalt Fiber leaf spring*
t_{CF}	-	*Thickness of CFRP leaf spring*
t_{EG}	-	*Thickness of E – Glass leaf spring*

t_{SS} - *Thickness of structural steel leaf spring*

t_T - *Thickness of Technora H leaf spring*

V_{BF} - *Volume of Bassalt Fiber leaf spring*

V_{CF} - *Volume of CFRP leaf spring*

V_{EG} - *Volume of E – Glass leaf spring*

V_{kw} - *Kerb Weight of the Vehicle*

V_{pl} - *Pay load of the Vehicle*

V_{SS} - *Volume of structural steel leaf spring*

V_T - *Volume of Technora H leaf spring*

W - *Load on the beam*

w_{BF} - *Width of Bassalt Fiber leaf spring*

w_{CF} - *Width of CFRP leaf spring*

w_{EG} - *Width of E – Glass leaf spring*

W_{ELS} - *Weight of the vehicle on eye of a Single Leaf Spring*

W_{LBF} - *Weight of Bassalt Fiber leaf spring*

W_{LCF} - *Weight of CFRP leaf spring*

W_{LEG} - *Weight of E – Glass leaf spring*

W_{LS} - *Weight of the Vehicle on a Single Leaf Spring*

W_{LSS} - *Weight of structural steel leaf spring*

W_{LT} - *Weight of Technora H leaf spring*

w_{SS} - *Width of structural steel leaf spring*

w_T - *Width of Technora H leaf spring*

W_t - *Total Weight of the Vehicle*

y - *Centroid of the beam*

Z - *Section Modulus of the beam*

δ_{max} - *Maximum deflection on the leaf spring*

ρ_{BF} - *Density of Bassalt Fiber leaf spring*

ρ_{CF} - *Density of CFRP leaf spring*

ρ_{EG} - *Density of E – Glass leaf spring*

ρ_S - *Density of structural steel leaf spring*

ρ_T - *Density of structural steel leaf spring*

σ_b - *Bending stress on the leaf spring*

ABSTRACT

Conventional steel leaf springs are the primary suspension system for the road vehicles. However, they are very heavy and account for 10-20% of the unsprung weight of the vehicle. Though, there is a possibility of reducing this weight in order to improve fuel economy. Hence, this thesis investigates the properties of CFRP, E – Glass, Technora H and BFRP leaf springs for lightweight vehicles through FEA of ANSYS software. The model is designed based on the design specifications acquired from Toyota Tacoma SR 2020 model. As such, Technora H leaf spring became the lightest leaf spring with 5.44 kg saving up to 73% of leaf spring weight of conventional steel leaf spring. In addition, all of the alternative leaf springs provide better fuel economy than the conventional steel leaf spring with Technora H offering the best fuel economy at 8.68 km/liter saving 44 liters of fuel per year that estimated at 3451 Birr per year. Moreover, the natural frequency for the first and second mode of transverse vibration for composite leaf springs are higher than the conventional leaf spring, with Technora H having highest first and second transverse natural frequency of 1179.8 Hz and 2482.3 Hz, respectively. Similarly, the amplitude of the transverse vibration of composite leaf springs are lower than that of conventional steel leaf spring, with Technora H having lowest amplitude of the transverse vibration of 0.000294 mm. This indicates that, the composite material, particularly Technora H, exhibit much lower vibration amplitudes, indicating better vibration isolation. Furthermore, all of the alternative leaf springs have a higher safety factor than the conventional steel leaf spring with E – Glass having highest safety factor of 3.77. Thus, MCLS have low weight, low fuel consumption, high safety factor, high transverse natural frequency, and low transverse vibration amplitude than conventional steel leaf springs. Therefore, MCLS can replace conventional steel leaf spring for the benefit of weight reduction and better fuel economy.

Keywords: *Fuel economy, Leaf Spring, Mono Composite, Weight.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background

In recent years, rising energy costs and environmental crises have made energy saving and pollution reduction a necessity for road vehicles (Qian et al., 2017). Fuel economy can be improved by using lightweight materials, optimizing the designs, and improving the manufacturing processes (Ashwini and Rao, 2018).

Lightweight vehicles are gaining significance in the automotive industry as they offer various benefits such as reduced fuel consumption, reducing greenhouse gas (GHG) emissions, improved performance, and enhanced safety (Lipshaw, 2020; Zou et al., 2022). These vehicles are designed to be lighter than traditional automobiles, achieved through the use of lightweight materials like aluminum, carbon fiber, and composites. As a result, they are growing in popularity among both consumers and manufacturers (Venkatesan and Devaraj, 2012).

Reducing vehicle weight is crucial for environmental sustainability and cost-effectiveness. Lighter vehicles require less energy to move, resulting in lower fuel consumption and reduced greenhouse gas emissions (Lipshaw, 2020). A 10% reduction in vehicle weight can result in a 6%-8% fuel economy improvement (U.S. Department of Energy, 2022). Furthermore, reducing vehicle weight can help to improve handling, which can enhance safety and driver satisfaction (Kulkarni and Khot, 2015). As such, automotive industry is actively pursuing lightweight vehicle design through various initiatives and research projects (Lipshaw, 2020).

Nowadays, majority of the road vehicles use leaf springs as their primary suspension system because of its low cost, easy maintenance, and high load-carrying capabilities (Aggarwal et al., 2022). Leaf springs are a common suspension component used in vehicles, particularly in heavy-duty applications such as trucks and trailers. They are made up of a series of thin, curved metal plates that are stacked together. Leaf springs are relatively simple and inexpensive to manufacture, and they are also very durable (Assarudeen and Anandkumar, 2015).

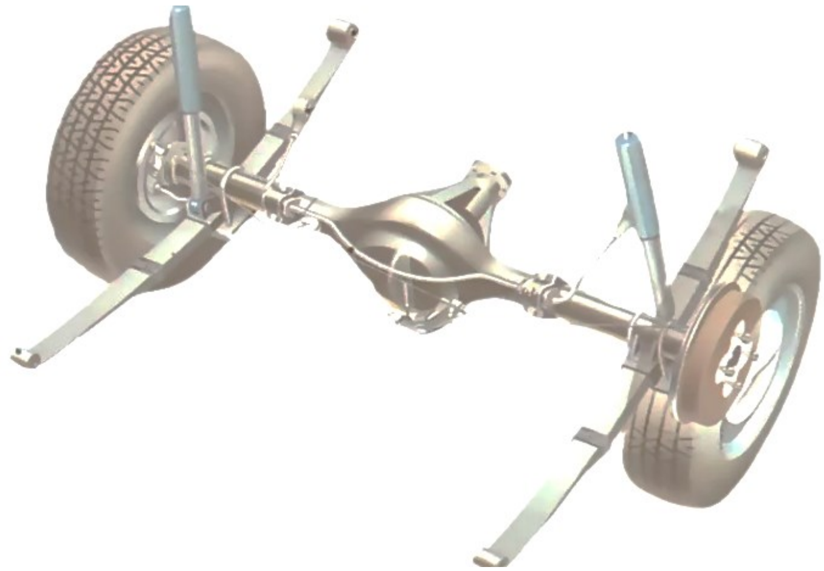


Figure 1.1: Typical Leaf Spring in vehicle suspension system (Fernie, 2016)

Leaf springs come in various types, as shown in *Figure 1.2*. The most common type of the leaf spring is the semi-elliptical leaf spring, which consists of multiple metal plates that taper in width and length. The master leaf, the longest plate, is attached to the vehicle frame, while the helper leaves are connected to the axle. Another type, the quarter-elliptical leaf spring, features a single leaf curved in a quarter-circle shape, often found in racing applications (Batu et al., 2021).

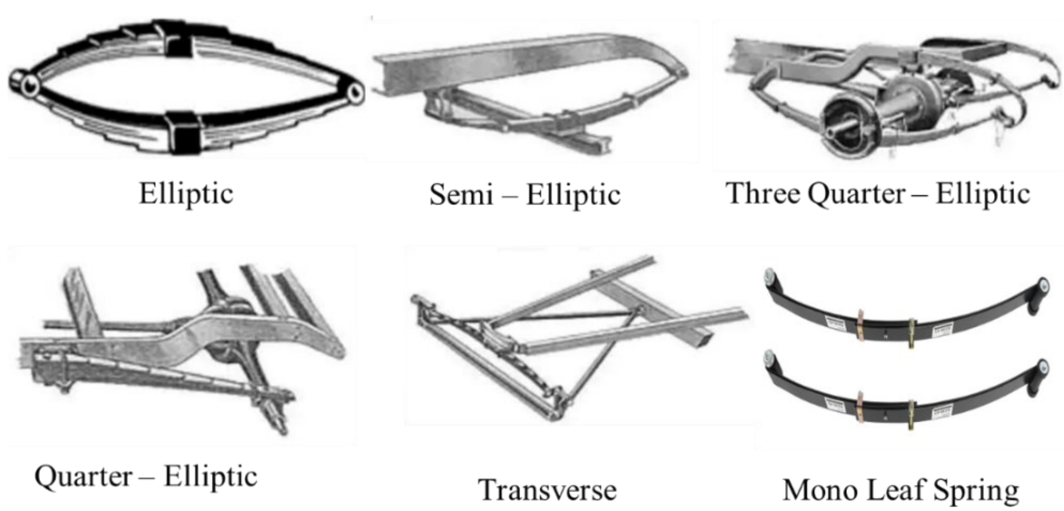


Figure 1.2: Various types of leaf springs (Degu, 2022; Fernie, 2016)

The three-quarter elliptical leaf spring combines characteristics of the semi-elliptical and quarter-elliptical springs, with two leaves, the top one curved in a three-quarter-circle shape. The transverse leaf spring is mounted perpendicular to the frame and commonly used in front suspensions. Lastly, the cantilever leaf spring is mounted at one end and commonly employed in heavy-duty applications (Batu et al., 2021).

Figure 1.3: Conventional Leaf Spring on heavy duty vehicles (Batu et al., 2021).

Traditional leaf springs are typically made of steel and consist of multiple layers of curved metal strips that are bolted together, have been widely used in vehicles. Steel leaf springs are durable and provide good load-carrying capacity (Bhandari and Patel, 2014).

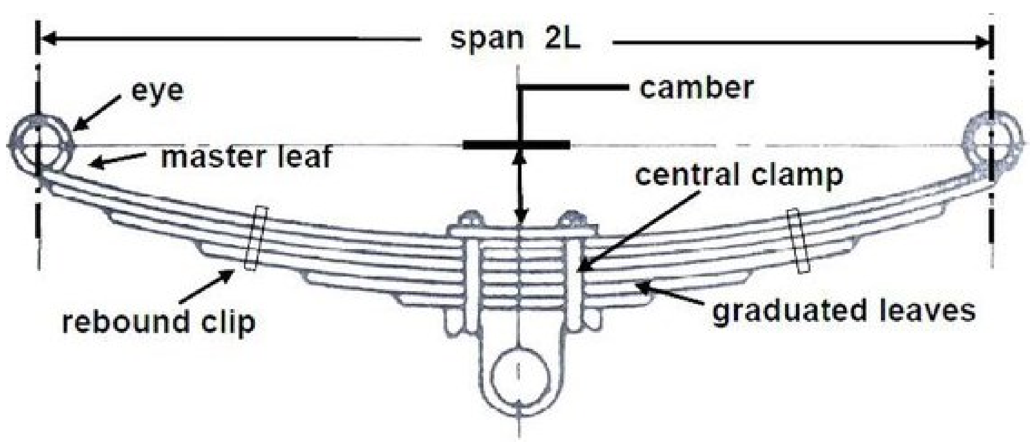


Figure 1.4: Various parameter of Conventional leaf Spring (Batu et al., 2021).

However, these designs have limitations in terms of weight, durability, and performance. They are relatively heavy, which affects the overall weight of the vehicle, leading to increased fuel consumption. Additionally, steel leaf springs are prone to corrosion, as shown in *Figure 1.5*, reducing their lifespan and durability (Bidve and Billore, 2022).

Figure 1.5: Corrosion in Traditional Leaf Spring (Fernie, 2016)

The conventional steel leaf springs account for 10-20% of unsprung weight (Chavhan and Wankhade, 2019). This shows that leaf springs are a potential area for weight reduction to reduce fuel consumption of the vehicles. Thus, several attempts, including replacement of the conventional material with composites, have been made in the last decade to reduce its weight without compromising performance. Composite materials are combination of two or more substances which have different physical or chemical properties and are combined to obtain properties different from the individual components (Ashwini and Rao, 2018).

In the case of suspension system, vibrations, shocks, and bump loads should be absorbed by the leaf springs, stored, and then released slowly (Ke et al., 2019). Hence, stress distribution property is very important as it directly reflects the load carrying capacity along the length, thickness, and width directions of the components (Ma et al., 2021).

Due to the limitations of traditional leaf springs, a number of alternative solutions are being explored. One of the most promising alternatives is the mono composite leaf spring (Mosleh et al., 2022). Mono composite leaf springs are made from a single piece of composite material (Varma et al., 2020). Composite materials are made up of two or more materials that are combined to create a new material with superior properties (Sajan and Selvaraj, 2021). Mono composite leaf springs are made of a single piece of composite material, typically fiberglass or carbon fiber, that is molded into the desired shape. They are significantly lighter, and they are also more durable and resistant to fatigue failure. Additionally, they are quieter and transmit fewer vibrations into the vehicle (Krishna et al., 2020).

In the past two decades, considerable efforts have been made to develop composite leaf springs as a lighter weight and more durable alternative to traditional steel leaf springs. Composite leaf springs can serve a greater range in terms of strength and flexibility. With advances in carbon fiber and aramid fiber technology, the strength-to-weight ratio is far greater than that of the traditional steel counterpart. Additionally, the fatigue life of the leaf springs can be increased with composite materials due to their ability to flex and resist corrosion better than steel (Ma et al., 2021). The use of composites also enables the possibility of custom designs, allowing for a variety of properties to be tailored to meet specific requirements (Chavhan and Wankhade, 2019). However, because of complexity of the manufacturing processes, the production of composite leaf springs are still underdeveloped and requires further researching (Ashwini and Rao, 2018). As a newer technology, composite leaf springs are expected to gain further traction in the automotive industry as their development progresses and costs become more affordable.

Therefore, in this thesis, the properties of mono composite materials for the application of leaf springs are tested under various working conditions, their characteristics are identified, and an improved leaf spring for lightweight vehicles are designed. Then, optimal materials were identified and an improved leaf spring was designed for lightweight vehicles.

1.2. Problem Statement

In the automotive industry, clean, fuel-efficient, and safe transportation are focus areas of research today. In order to improve fuel economy, one method is to reduce the weight of the components. Today, steel leaf springs are the primary suspension system for the road vehicles. However, the traditional steel leaf springs are very heavy and account for 10-20% of the unsprung weight (Chavhan and Wankhade, 2019). As a result, there is a possibility of reducing weight in order to improve fuel economy. Though, the analysis of leaf spring is not all about weight reduction. It should also include, the impact on fuel economy, vibration, and fatigue analysis. Over the past decade, several efforts have been made to reduce its weight by replacing steel with composite materials. But various literatures, usually, focus on single analysis. However, every day new composite materials with potentials for automobile applications emerge. Thus, their compatibility for the function of the leaf spring is to be investigated. Hence, still there is a need for further research on optimizing composite leaf springs. Therefore, this thesis investigates the properties of various composite materials including structural, modal, vibration and fatigue analysis for leaf springs and design an improved version for lightweight vehicles through finite element analysis, and investigate the relationship between the weight reduction and fuel economy of lightweight vehicles.

1.3. Research Question

This thesis is focused on the following research questions:

- What is the effect of replacing steel leaf springs with lightweight mono composite leaf springs on the unsprung mass of lightweight vehicles?
- What is the effect of replacing steel leaf springs with lightweight mono composite leaf springs on the fuel economy?
- How to analyze the performances of conventional leaf spring and mono composite leaf springs using FEA tools?

1.4. Objective

1.4.1. General Objective

The general objective of this thesis is to perform modeling and FEA of a mono composite leaf spring for lightweight vehicles for weight reduction and improve fuel economy.

1.4.2. Specific Objectives

The specific objectives of this thesis are:

- To analyze the effect of replacing steel leaf springs with lightweight mono composite leaf springs on the unsprung mass of lightweight vehicles,
- To analyze the effect of replacing steel leaf springs with lightweight mono composite leaf springs on the fuel economy, and
- To analyze the performances of conventional leaf spring and mono composite leaf springs using FEA tools.

1.5. Scope of The Study

This thesis aims to test properties various composite materials for leaf springs application for lightweight vehicles with the targeted aim of improving the fuel economy. This includes testing the mechanical properties of the materials under various working conditions using FEM analysis tools like ANSYS. However, the production or manufacturing of the prototype is not under the scope of this study.

1.6. Significance of The Study

Since vehicle weight is one of the most significant contributors towards the overall energy consumption of the vehicle, it is important to consider the various techniques to reduce it. Various approaches such as replacing the traditional materials of the components with light weight composites can contribute significantly in reducing the overall weight and improving fuel economy. This study aims to analyze performance of various composite materials for leaf spring application, to identify the optimal materials and design of an improved light weight composite leaf spring for lightweight vehicles. Therefore, the results would help automotive industries to improve fuel economy without sacrificing functionality requirements.

1.7. Organization of The Thesis

This thesis work is divided into seven chapters. **Chapter One** serves as an introduction, providing background information on leaf springs with the detail focus on composite leaf springs used in suspension systems of lightweight vehicles. Moreover, it introduces the problem statement, study objectives, scope, and thesis structure. Whereas, **Chapter Two** of the thesis reviews recent research on composite leaf springs and their effect on the weight reduction and fuel consumption. In addition, the identified research gap is included in this chapter.

In **Chapter Three**, possible strategies, materials and tools required, and methods used for the research are explained. A flow chart is also provided to show the working pattern and flow of the thesis. This chapter offers a detailed description of the steps taken to complete this thesis.

Chapter four of the thesis explores conceptual design of mono composite leaf spring for lightweight vehicle. Whereas, **Chapter Five** explores the design, modeling and finite element analysis of mono composite leaf spring are performed with respect to reducing the vehicle weight and improve fuel economy. And, essentially, **Chapter Six** of the thesis compares and discusses the results of chapter five. It presents the findings through charts and tables. And, finally, **Chapter Seven** of the thesis presents conclusions and recommendations based on the insights gained from chapter five. In addition, a list of references and appendices that contain additional information are included in the document of this thesis.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Weight Reduction and Fuel Economy

One of the biggest elements influencing a car's fuel efficiency is its weight (Bidve and Billore, 2022). In today's transportation world, the link between vehicle weight and fuel efficiency is critical. Broadly speaking, it may be said that a vehicle's tendency to use more fuel grows with its weight (Cheah and Heywood, 2010). It requires more energy to accelerate, brake, and maintain speed with a larger vehicle. This is mostly because moving a bigger vehicle requires more energy. To move the car forward, the engine must work harder and use more fuel (Faris et al., 2011). Consequently, lowering a vehicle's weight is essential to increasing both its fuel economy and efficiency (Greene, 2010).

A study by the Massachusetts Institute of Technology found that for every 100-kg reduction in vehicle weight, fuel economy improves by about 0.4 Liters per 100 km for cars and about 0.5 Liters per 100 km for light trucks. This means that a 10% reduction in vehicle weight can lead to a 6-8% improvement in fuel economy (Cheah and Heywood, 2010).

There are several methods for reducing the weight of a vehicle (Zhou et al., 2016). Using lighter materials, such carbon fiber and aluminum, is one method. These materials can be utilized to make parts that are lighter yet just as strong as steel since they are stronger than steel (Manaba and Hashe, 2021). In order to improve total fuel efficiency and lower fuel consumption, lightweight vehicles are essential. Because less energy is needed to move the car as a result of the weight decrease, fuel efficiency is increased (Ke et al., 2019).

Furthermore, lightweight vehicles offer numerous benefits beyond fuel economy. They tend to have better acceleration, handling, and braking capabilities due to their reduced mass (Sajan and Selvaraj, 2021). This not only enhances the driving experience but also contributes to overall road safety. Additionally, lightweight materials can be recycled more easily, reducing the environmental impact of vehicle production and end-of-life disposal (Zou et al., 2022).

Lightweight vehicles are becoming increasingly important as we move towards a more sustainable future (H. V. Kumar et al., 2021). Government regulations and consumer demand for fuel-efficient vehicles are driving the adoption of lightweight technologies in the automotive industry. Stricter fuel economy standards, such as those imposed by the Corporate Average Fuel Economy (CAFE) regulations in the United States, incentivize automakers to invest in weight reduction strategies to meet these requirements (Cheah and Heywood, 2010). The automotive industry is investing heavily in research and development of new lightweight materials and technologies. Advanced manufacturing techniques, such as structural bonding and innovative joining technologies, are being employed to ensure the durability and crashworthiness of lightweight vehicles. This ensures that lightweight materials can be used effectively without compromising passenger safety (Greene, 2010).

The use of lightweight components extends beyond the body and chassis of vehicles (Jaiswal et al., 2022). Interior components, including seats, panels, and trim, are being redesigned using lightweight materials to further reduce the vehicle's overall weight (Yang et al., 2019).

2.2. Leaf Springs and Suspension Systems

One of the most crucial parts of a car is the suspension system (Jadhao and Dalu, 2014). It is in charge of maintaining the tires' contact with the pavement, delivering a smooth ride, and absorbing vibrations from the road. Additionally, a well-designed suspension system can enhance the car's braking and handling capabilities (Saini et al., 2013). Generally speaking, control arms, dampers, and springs make up a suspension system. The dampers regulate the rebound of the springs and keep the car from overly bouncing, while the springs sustain the weight of the vehicle and cushion shocks from the road. The wheels can move up and down independently of one another and are kept in alignment by the control arms (Kapadia et al., 2016).

Conventional steel leaf springs have been widely used in vehicle suspension systems for many years. They are flexible, long, and slender strips of steel that are stacked on top of each other, forming a curved shape (Mahanthi and Murali, 2017). They consist of several layers of steel strips, also known as leaves, that are clamped together at the center. The longest plate is called the main leaf, and the shorter plates are called the graduated leaves. The graduated leaves are progressively shorter, with the shortest leaf at the center (Venkatesan and Devaraj, 2012). The leaves are tapered in shape to distribute the load evenly, with the longest leaf providing the primary support. This design allows the spring to flex and absorb shocks encountered during driving. The amount of flex depends on the stiffness of the leaf spring and the weight of the vehicle (Mundale et al., 2017).

The axle of the car is where one end of the leaf spring is fastened, and the chassis is where the other end is fastened (Varma et al., 2020). The occupants have a better ride because the leaf spring flexes to absorb impact when the car encounters a bump in the road. In addition, leaf springs are crucial for maintaining tire contact with the road and axle location (Nutalapati, 2015). They support the steering and braking capabilities of the car as well as helping to regulate the ride height and body roll (Chavhan and Chilbule, 2018).

The simplicity of leaf springs is one of their main benefits. They are simple to produce, maintain, and replace thanks to their uncomplicated design. They are a popular option for commercial vehicles like vans and trucks, SUVs, and train carriages since they are also less expensive to manufacture than other types of springs (Ashwini and Rao, 2018). Coil springs convey the load to a single point, while leaf springs distribute it more evenly across the vehicle's chassis. Furthermore, leaf springs are a great option for heavy-duty applications like trucks and commercial vehicles because of their exceptional load-carrying capabilities (Huang and Dao, 2016).

However, leaf springs do have some disadvantages. One significant drawback is their limited adjustability and suspension tuning options. Unlike more advanced suspension systems, leaf springs cannot be easily adjusted to fine-tune the vehicle's ride characteristics (Tadesse and Fatoba, 2022). Additionally, leaf springs can be prone to sagging over time, which can negatively impact the vehicle's ride quality and handling. Moreover, leaf springs can be quite heavy. This can add to the unsprung weight of the vehicle, which can reduce ride comfort and handling performance (Rai and Saxena, 2013).

The buildup of stress and ride comfort can both be significantly impacted by reducing unsprung weight. The weight of the car that is not supported by the suspension system, such as the brakes, tires, and wheels, is known as unsprung weight (Chavhan and Wankhade, 2019). In addition to increasing ride comfort, reducing unsprung weight can enhance handling, braking, and acceleration performance. The unsprung weight of leaf springs can be decreased by employing lightweight materials, such as composite materials or high-strength steel alloys (Umanath et al., 2020). Weight loss like this can lead to better overall ride quality and better suspension response (Kong et al., 2016).

Using lightweight leaf springs can help reduce fuel consumption. Lowering the suspension system's weight also lowers the vehicle's total weight, which may increase fuel economy (Qian et al., 2017). Composite materials, such fiberglass or carbon fiber, are lighter than steel but yet maintain the required rigidity and strength, making them suitable for use in lightweight leaf spring construction. In the current automotive sector, where there is a rising emphasis on decreasing carbon emissions and boosting fuel efficiency, this is especially crucial (Rajamanickam et al., 2022). Moreover, lightweight leaf springs can enhance directional stability and handling. It is possible to reduce the vehicle's center of gravity and improve stability when cornering and maneuvering by lowering the weight of the suspension parts (Utami et al., 2022).

In recent years, advancements in materials and manufacturing techniques have led to the development of innovative leaf springs (Paramitha et al., 2022). These include composite leaf springs made from fiberglass or carbon fiber-reinforced polymers, which offer even greater weight reduction and improved performance compared to traditional steel leaf springs (Ravindra et al., 2014).

2.3. Composite Materials in Automotive Industry

Composite materials are composed of two or more constituent materials, each having unique chemical and physical properties, that together give rise to a material with better properties than either would have on its own (Batu et al., 2021). Numerous advantages are provided by these materials, such as a high strength-to-weight ratio, resistance to corrosion, and design flexibility. Because of their excellent strength-to-weight ratio, resistance to corrosion, and longevity, composite materials are widely used in a variety of industries, including the automotive, marine, and aerospace industries (Wang et al., 2018).

Composite materials are employed in many different applications in the automotive industry, such as body panels, bumpers, hoods, trunks, frames, leaf springs, engine components, chassis components, and interior sections (Salman et al., 2018). They are employed to lighten cars, increase fuel efficiency, and improve performance (Bhandari and Patel, 2014).

The capacity of composite materials to minimize weight is one of their main benefits in the automotive sector. Due to their relative weight, traditional vehicle materials like steel and aluminum increase pollutants and fuel consumption (Li et al., 2022). Automakers may lower the weight of their cars considerably by employing composite materials, which improves fuel efficiency and lessens environmental impact (Katu et al., 2015). For instance, U.S. Department of Energy research discovered that weight reduction of up to 50% was possible when carbon fiber was substituted for steel in the body construction of a standard passenger car. Up to a 35% increase in fuel efficiency could result from this (Office of Energy Efficiency and Renewable Energy, 2022).

2.4. Mono Composite Leaf Springs

Suspension systems composed of a single piece of composite material are known as mono composite leaf springs, or MCLS (Katu et al., 2015). The purpose of these springs is to swap out conventional steel leaf springs in cars. Comparatively speaking, they are stronger and lighter than conventional steel leaf springs (Shukoor and Rao, 2017). Additionally, they have greater resistance to wear and corrosion. As opposed to steel leaf springs, MCLS can be made to offer a superior ride and handling (A. Kumar et al., 2014).

Because MCLS can save weight, they are being investigated for lightweight vehicles (Kulkarni and Khot, 2015). Compared to conventional leaf springs composed of steel or other metals, MCLS can be substantially lighter thanks to the use of composite materials. Weight loss like this improves performance and fuel efficiency (Degu, 2022). Furthermore, MCLS can be adjusted to meet particular load needs, enabling the best possible suspension performance. In addition, they have a longer service life and require less maintenance than conventional steel leaf springs since they are stronger and more corrosion-resistant (Varma et al., 2020).

When utilized in lightweight cars, MCLS have many advantages. First off, MCLS are usually 50–70% lighter than conventional steel leaf springs (Jaiswal et al., 2022). This lowers the vehicle's weight and increases fuel economy, enabling it to run on less energy while still performing as intended. Second, because MCLS have a larger damping capacity than conventional leaf springs, they provide a more comfortable ride. This implies that MCLS can lessen vibrations and shocks more successfully, giving the passengers a smoother and more comfortable ride (Yang et al., 2019). In addition, they last longer and are more resilient than conventional steel leaf springs. Because MCLS generate less noise than conventional steel leaf springs, driving enjoyment is enhanced overall (Jadhao and Dalu, 2014).

There are unique difficulties in the design and production of MCLS. Ensuring the appropriate selection and assembly of composite materials to attain the intended mechanical properties presents a problem (Saini et al., 2013). During the design phase, it is necessary to take into account factors like fatigue resistance, manufacturing feasibility, and material stiffness. Despite these difficulties, MCLS is becoming more and more popular in lightweight cars. MCLS are a desirable option for contemporary cars because they offer a special blend of lightweight construction, increased durability, and improved comfort (Kapadia et al., 2016).

2.5. Materials for Mono Composite Leaf Springs

MCLS uses a variety of composite material types. Aramid fiber reinforced polymer (AFRP), glass fiber reinforced epoxy, carbon fiber reinforced epoxy, hybrid polymer composite, carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP), and natural fiber reinforced polymer (NFRP) are among the materials that are most frequently employed (Jadhao and Dalu, 2014).

Glass fiber-reinforced epoxy offers specific strength, modulus, and strain energy properties. Carbon fiber-reinforced epoxy provides higher specific strength, modulus, and strain energy.

Hybrid polymer composite combines conventional steel and polymer composite for mechanical performance (Mundale et al., 2017). CFRP consists of carbon fibers embedded in a polymer matrix, offering high strength-to-weight ratio, fatigue resistance, and corrosion resistance. GFRP comprises glass fibers embedded in a polymer matrix, providing stiffness, moderate strength, and cost-effectiveness. AFRP, also known as Kevlar, combines aramid fibers with a polymer matrix, offering exceptional impact resistance and strength. NFRP involves natural fibers embedded in a polymer matrix, offering low cost, reduced environmental impact, and vibration damping properties (Varma et al., 2020).

The performance of MCLS is largely dependent on the mechanical characteristics of the composite materials. Composite leaf springs' load-bearing capacity is influenced by the fiber's volume content and laying angle, whereas stiffness is largely determined by the kind of matrix used (Nutalapati, 2015). Moreover, composite leaf springs have a higher natural frequency than steel leaf springs. Fatigue strength, corrosion resistance, and damping capacity are further mechanical characteristics of composite materials that are crucial for MCLS applications. Because composite materials have a high fatigue strength, they can be repeatedly loaded and unloaded without breaking down (Ashwini and Rao, 2018). Furthermore, composite materials are capable of absorbing energy and reducing vibration due to their strong damping ability (Kulkarni and Khot, 2015).

Composite leaf springs are made using several manufacturing techniques. The first step is fiber pre-treatment, which includes cleaning, sizing, and drying the fibers. Next, the fibers are impregnated with a polymer resin using techniques like hand lay-up, filament winding, or resin transfer molding (Manchanda et al., 2015). Once the fibers are impregnated, they are shaped into leaf spring profiles using compression molding or autoclave curing. Post-curing is then conducted to ensure the composite material reaches its desired properties. Finally, the leaf springs are trimmed, inspected, and tested for quality assurance (Singh and Rastogi, 2021).

2.6. Review of Previous Studies on Leaf Springs and Their Impact on Vehicle Weight and Fuel Economy

Researchers have conducted several studies on the design and analysis of composite leaf springs. (Bidve and Billore, 2022) conducted a study on the design and analysis of a single composite leaf spring for light-weight vehicles. The researchers found that composite leaf springs can offer significant weight reduction up to 75%, compared to steel leaf springs, while maintaining or even improving stiffness and strength. They also found that composite leaf springs can have a longer fatigue life than steel leaf springs.

(A. Kumar et al., 2014) conducted a study on the optimization of composite leaf spring design using FEA. The researchers found that the optimal design of a composite leaf spring depends on a number of factors, including the type of composite material used, the layup configuration, and the thickness of the laminates. They also found that FEA can be a valuable tool for designing composite leaf springs that meet specific performance requirements.

(Mehndiratta et al., 2015) conducted a study on the fatigue life of composite leaf springs made from GFRP. The researchers found that the fatigue life of GFRP leaf springs is significantly affected by the stress level and the number of loading cycles. They also found that the fatigue life of GFRP leaf springs can be improved by using a higher fiber volume fraction and a more fatigue-resistant resin.

(Shukoor and Rao, 2017) conducted a study on the impact behavior of composite leaf springs. The researchers found that composite leaf springs can absorb more energy than steel leaf springs when subjected to impact loading. They also found that the impact behavior of composite leaf springs can be improved by using a higher fiber volume fraction and a more impact-resistant resin.

(Singh and Rastogi, 2021) conducted a study on the corrosion resistance of composite leaf springs. The researchers found that composite leaf springs are more resistant to corrosion than steel leaf springs. They also found that the corrosion resistance of composite leaf springs can be further improved by using a corrosion-resistant resin.

(Kessentini et al., 2019) studied characteristics of carbon fiber reinforced polymer leaf springs using finite element analysis approach for the SUVs application. The objective of the work as to reduce the weight of the leaf spring without sacrificing performance requirements. They optimized the design parameters such as fiber diameter, fiber length, percentage volume of fibers and orientation angle of the fibers in a mono polymer composite leaf spring. The effects of these parameters on the deflection, bending stress, spring rate, stiffness and von-mises stress under different loading conditions were investigated. From the result, they claimed that the carbon fiber reinforced polymer leaf springs can provide a better high strength-to-weight ratio than the traditional steel counterpart. However, they did not give any guidance regarding the manufacturing processes.

(Yang et al., 2019) studied the influence of layer thickness and ply angle variation of rectangular cross-section E-glass reinforced composite leaf springs to improve performance and reliability. They used ANSYS to predict the effect of the considered parameters under various loading conditions. They observed that the stiffness of the spring increases linearly with the increase of ply thickness and varies nonlinearly with the variation of the ply angle. Even though they indicated the need of tuning the ply angle of the reinforcing ingredients involved in the preparation of the composite leaf springs, they did not provide the optimal angle of the plies for the best performance.

(Nutalapati, 2015) compared performance of steel leaf spring with glass fiber reinforced polymer composite leaf spring based on stresses, deformations and weight saving constraints using ANSYS software. The objective of the study if the light weight composite leaf spring can play the role of the traditional steel counterpart. Both types of the leaf springs were subjected to the same loads under several conditions. He concluded that, to provide the same performance requirements, the weight of glass fiber reinforced polymer composite leaf spring can be reduced up to 85% compared to steel material.

(Krishnamurthy et al., 2020) designed a composite leaf spring for heavy-duty commercial vehicles and conducted FEA on assembly of the suspension system using ANSYS software. The objective of the research was to find light weight material that can provide the required performance at a reasonable cost. They concluded that the new material is more economical and has less weight, but relatively expensive when compared to the conventional material.

2.7. Research Gap

The above-mentioned literatures, in general, show that composite leaf springs have a longer lifespan and are better at resisting fatigue and corrosion than steel. In addition, they have a higher stiffness to weight ratio, making them an attractive alternative to reduce weight. However, because of complexity of their manufacturing processes, the production processes of composite leaf springs are underdeveloped and requires further researching. Moreover, every day new composite materials with potentials for automobile applications emerge. Thus, their compatibility for the function of the leaf spring is to be investigated. As such, various literatures have studied the potential of composite materials to replace the conventional steel leaf springs. Though, the analysis of leaf spring is not all about weight reduction. It should also include, the impact on structure, vibration, and fatigue analysis. But various literatures, usually, do not focus on integrated analysis. Therefore, this thesis investigates the properties of various composite materials including structural, modal, vibration and fatigue analysis for leaf springs and design an improved version for lightweight vehicles through finite element analysis, and investigate the relationship between the weight reduction and fuel economy of lightweight vehicles.

CHAPTER THREE

3. MATERIALS AND METHODOLOGY

In order to improve fuel economy, properties of various composite materials for leaf springs were investigated and mono composite leaf spring was designed and modeled. The study emphasizes the model and analysis composite materials for leaf springs using FEA tools under various loads with the aim of reducing vehicle weight and improving fuel economy. The methodology for design and modeling can be broken down into several steps.

3.1. Research Design

This thesis focusses on modeling and analyzing a mono composite leaf spring for lightweight vehicles to reduce the vehicle weight and improve its fuel economy. The study will use a mixed-methods approach, combining quantitative and qualitative data collection methods. The quantitative data survey will focus to collect data on the general specification of the vehicle, the dimensions and the weight of the vehicle. Therefore, data is collected from the manufacturer of the selected vehicle. The qualitative data focusing on the methods, approaches and procedures of the leaf spring and composite material were collected through document review. The thesis will identify the most feasible material for the leaf spring of the selected vehicle. In addition, it will analyze the mono composite leaf spring using FEA. Moreover, the thesis will investigate the effect of the material of the leaf spring on vehicle weight and fuel economy.

3.2. Materials

This thesis aims to identify the optimal materials for mono composite leaf spring and design an improved composite leaf spring for light duty vehicles. To achieve this, properties of several composite materials such as, polymer matrix composites (PMCs) and glass-fiber reinforced polymers (GFRPs) were investigated analytically and using FEA.

3.2.1. Structural Steel

Structural steel is a high-strength, versatile construction material primarily composed of iron with a small percentage of carbon and various alloying elements like manganese, silicon, and others. Its general properties include exceptional tensile strength, durability, and the ability to withstand heavy loads and environmental factors, making it a cornerstone in the construction and engineering industries for various structural applications, including buildings, bridges, and industrial machinery (Aggarwal et al., 2022). However, traditional structural steel leaf springs can be heavy, negatively impacting the overall weight of the vehicle and subsequently its fuel efficiency. Hence, the limitations of structural steel have led to the exploration of alternative materials, to reduce the weight of leaf springs and enhance fuel economy (Batu et al., 2021).

3.2.2. Carbon Fiber Reinforced Polymer

Carbon Fiber Reinforced Polymer (CFRP) is a composite material composed of carbon fibers and a polymer matrix, typically epoxy (Abbood et al., 2021). Carbon fibers are extremely strong and light fibers that are refined to consist almost exclusively of carbon. The polymer matrix provides protection and grasp on the fiber along with toughness (Rajak et al., 2019). CFRP have high strength, stiffness, and fatigue resistance, as well as low thermal conductivity and weight (Abbood et al., 2021). It finds extensive applications in aerospace, automotive, sports equipment, and construction due to its ability to reduce overall weight and increase structural integrity (Zardi & Kolur, 2019). However, it can be expensive to produce and has challenges in tool wear and tool life when machining (Assarudeen and Anandkumar, 2015). Despite these limitations, CFRP has the potential to replace structural steel in the applications of vehicle’s leaf spring in order to reduce the weight of the leaf spring. This would result in improved fuel efficiency and reduced emissions (Aggarwal et al., 2022). Thus, CFRP is considered for MCLS due to its low weight, high strength, high stiffness and high strength.

3.2.3. Glass Fiber Reinforced Polymer

Glass Fiber Reinforced Polymer (GFRP) is a composite material composed of glass fibers embedded in a polymer matrix, commonly epoxy or polyester resin (Abbood et al., 2021). E-

Glass, or electrical glass, is one of the most widely used glass fiber types in composites, known for its electrical insulation properties and resistance to chemical and environmental factors (Rajak et al., 2019). E-Glass composites find applications in marine construction, automotive parts, wind turbine blades, and even aircraft components. The advantages of E-Glass composites include their lightweight nature, corrosion resistance, and ease of manufacturing (Aggarwal et al., 2022). However, they have limitations such as lower strength compared to carbon fiber composites and susceptibility to impact damage (Assarudeen and Anandkumar, 2015). When considering the potential of E-Glass in replacing structural steel in vehicle leaf springs, the material's lightweight and corrosion-resistant properties make it a promising candidate to reduce the weight of leaf springs (Chavhan and Chilbule, 2018). Thus, GFRP is considered for MCLS due to its low weight, corrosion resistance, and ease of manufacturing.

3.2.4. Aramid Fiber Reinforced Polymer

Aramid Fiber Reinforced Polymer (AFRP) is made up of aramid fibers embedded in a polymer matrix, usually epoxy resin (Abbood et al., 2021). Aramid fibers are recognized for their superior heat and impact resistance, low weight, and great tensile strength. Because of the strong orientation of the fibers along the fiber axis, a larger percentage of the chemical bond contributes to the strength of the fiber, more so than in many other synthetic fibers (Aggarwal et al., 2022). Aramid fibers come in several forms, such as para- and meta-aramid. Because of its extreme abrasion resistance and flexibility, it is the perfect material for high-strength ropes and braids. Technora H is used in many different applications, such as protective gear, automotive parts, aerospace, and athletic equipment, because of its exceptional strength and durability combined with a lightweight profile (Degu, 2022). Technora H and other AFRP composites can be somewhat pricey, and they could not be as stiff as carbon fiber composites. Technora H has a great deal of potential to replace structural steel in car leaf spring applications, which would lead to lighter vehicles and better fuel economy (Chavhan and Chilbule, 2018). Thus, Technora H is considered for MCLS due to its low weight, great flexibility, high tensile strength, and high impact resistance.

Table 3.1: Properties of Conventional Leaf Spring Material and Selected Composite Material (Abbood et al., 2021; Rajak et al., 2019)

	CFRP	E – Glass	Technora H	BFRP	Structural Steel
Density (Kg/m^3)	2100	2500	1390	2000	7850
Modulus of Elasticity (GPa)	75	72.4	70	60	200
Poisson's ratio	0.35	0.35	0.35	0.35	0.3
Fatigue Strength (MPa)	450	600	550	300	250
Tensile Strength (MPa)	2800	3450	3000	1200	550
Compressive Strength (MPa)	450	600	500	500	250
Shear Strength (MPa)	200	700	220	200	200
Water Absorption (%)	0.35	0.75	3	0.8	0.05
Elongation (%)	2.5	2.5	2.39	2	8
Coefficient of Linear Expansion ($10^{-6}/^{O}C$)	- 9.0	5.0	- 2.0	10	11.7

3.2.5. Bassalt Fiber Reinforced Polymer

Basalt Fiber Reinforced Polymer (BFRP) is a composite material comprising basalt fibers embedded in a polymer matrix, often epoxy resin (Abbood et al., 2021). Basalt fibers, derived from natural volcanic rock, offer a unique combination of properties, including high tensile strength, excellent resistance to corrosion and heat, and low environmental impact due to their abundance and sustainability (Aggarwal et al., 2022). BFRP composites have gained attention in various industries, such as construction, infrastructure, and automotive, for applications in reinforcing concrete structures, manufacturing lightweight components, and improving durability. BFRP offers a promising solution to reduce leaf spring weight, leading to enhanced fuel efficiency and reduced emissions (Venkatesan and Devaraj, 2012). Thus, BFRP is considered for MCLS due to its low weight, excellent corrosion resistance, and high tensile strength

3.3. Data Collection

In this thesis, a mixed-method approach was employed to collect data. The approach consists of two main methods: document review, and vehicle specification.

3.3.1. Document Review

A comprehensive review of relevant literature and documents related to composite materials, leaf springs and fuel economy are conducted. This will encompass studying literature on various types of composite materials, design and modeling of leaf springs, and the effect of weight reduction on the fuel economy. In addition, the part catalogue of Toyota Tacoma SR 2020 model is consulted. Moreover, the official Toyota Tacoma SR vehicle website (Toyota, 2020) is visited to investigate the detail component of the vehicle.

3.3.2. Vehicle Specification

For modeling and FEA of a mono composite leaf spring for lightweight vehicles to reduce the vehicle weight and improve its fuel economy, the specification of the selected vehicle and its leaf spring are required. Thus, the specifications of Toyota Tacoma SR 2020 model like that of overall dimensions, weight of the vehicle, fuel economy and the dimensions of the leaf spring are collected from the website of the manufacturer. For this particular thesis, Toyota Tacoma SR 2020 model, shown in *Figure 3.1*, is considered for the modeling of the mono composite leaf spring. Hence, the specification shown in *Table 3.2*, are collected accordingly.

Leaf springs are known for their durability and ability to handle heavy loads, making them suitable for trucks like the Tacoma. They offer a cost-effective and reliable suspension solution, particularly in rugged conditions or off-road scenarios. Leaf springs are relatively easy to maintain and repair, as individual leaves can be replaced if damaged or worn. Leaf springs can provide a stiffer ride compared to more advanced coil spring suspensions, potentially leading to a less comfortable on-road experience, especially when the truck is empty. They may be more prone to axle hop or wheel hop during heavy braking or acceleration, affecting traction and stability. Leaf springs have multiple components, including shackles and hangers, that require periodic maintenance to prevent wear and potential noise issues.

In 2020, Toyota produced several models of pickup trucks, each with its own unique features. Among these, Toyota Tacoma SR is the base trim level of the 2020 Toyota Tacoma lineup. It is designed to be a no-frills, affordable option for those who need a reliable midsize pickup truck without many extra features or high-end materials.

Figure 3.1: Toyota Tacoma SR 2020 Model (Seeger Toyota, 2020)

The rear suspension of the Toyota Tacoma SR typically features a multi-leaf spring pack, which consists of several individual leaves (strips of steel) arranged in multiple layers. The Toyota Tacoma SR leaf spring is responsible for supporting the rear axle of the truck. It also helps to absorb bumps and road vibrations, providing a smoother ride for the driver and passengers. It consists of three leaves, with two of the leaves being shorter and stacked on top of the longest leaf. The leaves are held together by U-bolts and spring clamps. The leaf spring has spring eyes at each end, which are used to attach the leaf spring to the truck's frame and axle. The leaf spring is arched, which helps to provide lift and support.

Table 3.2: Toyota Tacoma SR 2020 model (Seeger Toyota, 2020)

S.No.	Parameter		Value
1	Length (m)		5.39
2	Width (m)		1.89
3	Height (m)		1.79
4	Wheelbase (m)		3.23
5	Ground clearance (m)		0.239
6	Payload Capacity (Kg)		734.82
7	Curb Weight (Kg)		2032.1
8	Seating Capacity		6
9	Engine	Number of cylinders	4
		Displacement (Liter)	2.7
		Power (KW)	118.57
		Torque (Nm)	244.047
10	Transmission		5 (manual)
11	Drivetrain		2WD
12	Fuel Economy (Km/Liter)		8.503
13	Cargo and Bed Length (m)		1.54

The Toyota Tacoma SR, like other models in the Tacoma lineup, typically features leaf spring suspension in the rear to provide stability and support for the vehicle's payload and towing capacity. Leaf springs are a type of suspension system consisting of multiple layers of curved, tapered steel strips (leaves) stacked on top of each other.

Leaf springs are known for their durability and ability to handle heavy loads, making them suitable for trucks like the Tacoma. They offer a cost-effective and reliable suspension solution, particularly in rugged conditions or off-road scenarios. Leaf springs are relatively easy to maintain and repair, as individual leaves can be replaced if damaged or worn. Leaf springs can provide a stiffer ride compared to more advanced coil spring suspensions, potentially leading to a less comfortable on-road experience, especially when the truck is empty. They may be more prone to axle hop or wheel hop during heavy braking or acceleration, affecting traction and stability. Leaf springs have multiple components, including shackles and hangers, that require periodic maintenance to prevent wear and potential noise issues.

Table 3.3: Toyota Tacoma SR Leaf Spring (Seeger Toyota, 2020)

S.No.	Parameter	Value
1	Number of leaves	3
2	Length of master leaf (m)	0.7
3	Length of 2^{nd} leaf (m)	0.6
4	Length of 3^{rd} leaf (m)	0.4
5	Width (m)	0.0762
6	Leaf Thickness (m)	0.01
7	Width of U – bolt (m)	0.35

3.4. Data Analysis

The results of the data collection are basically two things. These are, the specification of the Toyota Tacoma SR 2020 model, and conventional steel leaf spring specification. Hence, these two results are recorded and analyzed accordingly.

3.5. Conceptual Design

After determining the technical specification of the Toyota Tacoma SR 2020 model, and its leaf spring's dimensions, the conceptual design of the leaf spring is performed. This was done by considering various materials for the leaf spring including conventional steel and selected composite materials.

3.6. CAD Modeling and Analysis

After the required specifications of the Toyota Tacoma SR 2020 model leaf spring are obtained through data collection, the software modeling of the conventional leaf spring and mono composite leaf spring was performed using CAD and FEA softwares. This includes the 3D modeling of the model and FEA. As part of the FEA, 3D CAD models were developed, boundary conditions were applied, and loads were applied to simulate operating conditions. SOLIDWORKS 2022 was used for CAD modeling, and ANSYS 2022 was used for Finite Element Analysis (FEA). Furthermore, Microsoft Excel is used for graphical analysis.

SOLIDWORKS is a widely-used Computer-Aided Design (CAD) software that is employed by millions of engineers worldwide (Solidworks, 2022). It is equipped with a comprehensive set of features and tools, enabling users to create drawings, perform design analysis, estimate costs, generate renderings, and create animations, among other functions (Capitol Technology University, 2019). Additionally, it facilitates analyses and simulations, including Finite Element Analysis (FEA) (Solidworks, 2022). Renowned for its user-friendly interface, extensive functionality, and broad range of capabilities, it has become a favored choice for engineers and designers across diverse industries and professions worldwide (Capitol Technology University, 2019).

ANSYS (Analysis System) is a leading engineering simulation software that offers a range of products for structural, fluid, and Multiphysics analysis, including ANSYS Mechanical, which is a finite element solver with structural, thermal, acoustics, transient, and nonlinear capabilities, and ANSYS Fluent, which is known for fluid simulation. The software offers a dynamic environment with a complete range of analysis tools, from preparing geometry for analysis to connecting additional physics for even greater fidelity (ANSYS, 2021). Overall, it is a powerful and versatile software that can be used for a range of engineering simulation and 3D design applications (Huang and Dao, 2016).

CHAPTER FOUR

4. CONCEPTUAL DESIGN OF LEAF SPRING

Leaf springs are made out of flat plates. They may carry lateral loads, brake torque, driving torque etc., in addition to shocks. They can be considered as a double cantilever beam, as shown in *Figure 4.1*, with a load W at the free end of the leaf spring and length L because it is mounted on the axle using U- bolts firmly (Khurmi and Gupta, 2005).

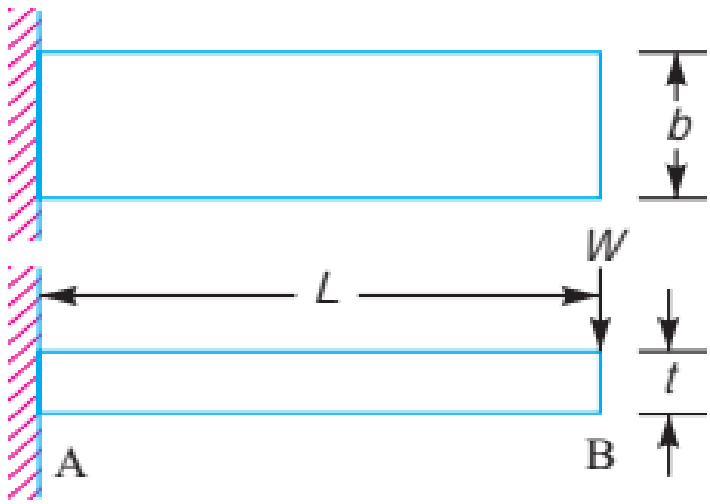


Figure 4.1: Cantilever type Leaf Spring (Khurmi and Gupta, 2005)

For cantilever shown in *Figure 4.1*, the maximum bending moment at the cantilever end A is:

$$M = WL \qquad \text{Equation 4.1}$$

Where,

- M is the maximum bending moment (Nm),
- W is the Load on the beam (N), and
- L is the Length of the beam (m).

Whereas, the section modulus of the beam can be determined from:

$$Z = \frac{I}{y} = \frac{bt^3/12}{t/2} = \frac{bt^2}{6} \qquad \text{Equation 4.2}$$

Where,

- Z is the section Modulus of the beam (m^3),
- I is the Moment of Inertia the beam (m^4),
- y is the Centroid of the beam (m),
- b is the width of the beam (m), and
- t is the thickness of the beam (m).

Moreover, the bending stress in such leaf spring can be determined from:

$$\sigma_b = \frac{M}{Z} = \frac{WL}{bt^2/6} = \frac{6WL}{bt^2} \qquad \text{Equation 4.3}$$

Where,

- σ_b is the bending stress on the leaf spring (Pa),
- M is the maximum bending moment (Nm),
- Z is the section Modulus of the beam (m^3),
- W is the Load on the beam (N),
- L is the Length of the beam (m).
- I is the Moment of Inertia the beam (m^4),
- b is the width of the beam (m), and
- t is the thickness of the beam (m).

Furthermore, the maximum deflection for a cantilever with concentrated load at the free end is given by:

$$\delta_{max} = \frac{WL^3}{3EI} = \frac{WL^3}{3Ebt^3/12} = \frac{4WL^3}{Ebt^3} \qquad \text{Equation 4.4}$$

Where,

- δ_{max} is the maximum deflection on the leaf spring (m),
- W is the Load on the beam (N),
- L is the Length of the beam (m).
- E is the Young's modulus of the leaf spring material (Pa),
- I is the Moment of Inertia the beam (m^4),

- b is the width of the beam (m), and
- t is the thickness of the beam (m).

In addition, the maximum deflection for a cantilever beam can be determined from:

$$\delta_{max} = \frac{2\sigma_b L^2}{3Et} \qquad \text{Equation 4.5}$$

Where,

- δ_{max} is the maximum deflection on the leaf spring (m),
- σ_b is the bending stress on the leaf spring (Pa),
- L is the Length of the beam (m).
- E is the Young's modulus of the leaf spring material (Pa), and
- t is the thickness of the beam (m).

Considering the Toyota Tacoma SR 2020 model, the total weight of the vehicle can be obtained as shown in *Equation 4.6*. The total weight of the vehicle comprises the kerb weight and payload of the vehicle. Payload of the vehicle is the load carrying capacity of the vehicle measured in terms of weight. It includes the passenger, cargo and other equipment the vehicle carries. Whereas, the Kerb weight of a vehicle is the weight of the vehicle itself without any passengers or items on or in it. Therefore, the total mass of the vehicle can be determined as:

$$\mathrm{M_t} = \mathrm{V_{pl}} + \mathrm{V_{kw}} \qquad \text{Equation 4.6}$$

Where,

- M_t is the total mass of the vehicle (Kg),
- V_{pl} is the pay load of the vehicle (Kg), and
- V_{kw} is the Kerb Weight of the Vehicle (Kg).

As shown in *Table 3.2*, payload of the vehicle and Kerb weight are 734.82 Kg and 2032.1Kg, respectively. Thus,

$$\mathrm{M_t} = 734.82 + 2032.1$$

$$\mathbf{M_t = 2,766.92\ Kg}$$

According to (Kalwaghe & Sontakke, 2014), the value of safety factor for vehicle ranges from 1.3 to 2.25, for vehicle components. Thus, taking the safety factor to be 1.5:

$$W_t = M_t g F_S \quad \text{Equation 4.7}$$

Where,

- W_t is the total weight of the vehicle (N),
- M_t is the total mass of the vehicle (Kg),
- g is the acceleration due to gravity (m/s^2), and
- F_S is the safety factor.

Thus, taking acceleration due to gravity to be 9.81 m/s^2, then:

$$W_t = 2766.92 * 9.81 * 1.5$$

$$\mathbf{W_t = 40,715.23\ N}$$

Since the vehicle under study is four-wheel vehicle, a single leaf spring corresponding to one of the four wheels, takes up one fourth of the total weight of the vehicle. That is:

$$W_{LS} = \frac{W_t}{4} \quad \text{Equation 4.8}$$

Where,

- W_{LS} is the weight of the vehicle on a single leaf spring, (N), and
- W_t is the total weight of the vehicle (N).

$$W_{LS} = \frac{40{,}715.23}{4}$$

$$\mathbf{W_{LS} = 10,178.81\ N}$$

Moreover, leaf spring consists of two eyes on the master leaf. Thus, the vehicle load on each eye of the spring can be determined from:

$$W_{ELS} = \frac{W_{LS}}{2} \quad \text{Equation 4.9}$$

Where,

- W_{ELS} is the weight of the vehicle on eye of a single leaf spring, (N), and
- W_{LS} is the weight of the vehicle on a single leaf spring, (N).

$$W_{ELS} = \frac{10{,}178.81}{2}$$

$$\mathbf{W_{ELS} = 5{,}089.4\ N}$$

Hence, 5089.4 N of the load rests on each eye of the leaf spring.

4.1. Conventional Structural Steel Leaf Spring

In order to determine the deflection and stress of the leaf spring, first, the effective length of the leaf spring must be determined. The leaf springs are usually mounted on the axle of the vehicle firmly either using Band or U bolt. According to (Khurmi and Gupta, 2005), the effective length of leaf spring can be calculated as :

$$2L_{eff} = \begin{cases} 2L_1 - l & \text{When Band is used} \\ 2L_1 - \frac{2}{3}l & \text{When U} - \text{bolt is used} \end{cases} \qquad \text{Equation 4.10}$$

Where,

- $2L_{eff}$ is the effective length of the leaf spring (m),
- L_1 is the total length of the leaf spring (m), and
- l is width of band or U – bolts (m).

Since U – bolt is used for clamping in the selected vehicle, the effective length of the leaf can be determined from:

$$2L_{eff} = 2L_1 - \frac{2}{3}l$$

Thus, taking the width of the U – bolt to be as shown in 0.35 m as shown in *Table 3.3*, the effective length of the leaf spring can be:

$$2L_{eff} = 2(0.7) - \frac{2}{3}(0.35)$$

$$\mathbf{2L_{eff} = 1.166\ m}$$

$$\mathbf{L_{eff} = 0.583\ m}$$

Hence, half effective length of the conventional steel leaf spring is 0.583 m.

Bending stress of the conventional steel leaf spring can be determined as follows:

$$\sigma_{Ls} = \frac{6W_{ELS}\mathrm{L_{eff}}}{nw_{SS}(t_{PSS})^2} \quad \text{Equation 4.11}$$

Where,

- σ_{Ls} is the bending stress of conventional steel leaf spring (Pa),
- L_{eff} is half of the effective length of the leaf spring (m),
- W_{ELS} is the weight of the vehicle on eye of a single leaf spring, (N),
- n is the number of leaves of the leaf spring,
- w_{SS} is the width of structural steel leaf spring (m), and
- t_{PSS} is the pack thickness of structural steel leaf spring (m).

$$\sigma_{Ls} = \frac{6 * 5089.4 * 0.583}{3 * 0.0762(0.03)^2}$$

$$\mathbf{\sigma_{Ls} = 86.53\ MPa}$$

Thus, 86.53 MPa of stress occurred around one eye of the conventional leaf spring.

As shown in *Table 3.1*, the compressive strength of the structural leaf spring is 250 MPa. Thus, the safety factor of this system can be determined from:

$$S_{FS} = \frac{\sigma_{Cs}}{\sigma_{Ls}} \quad \text{Equation 4.12}$$

Where,

- S_{FS} is the safety factor of the conventional structural steel leaf spring
- σ_{Cs} is the compressive strength of the conventional steel leaf spring (Pa),
- σ_{Ls} is the bending stress of conventional steel leaf spring (Pa),

Hence,

$$S_{FS} = \frac{250 * 10^6}{86.53 * 10^6}$$

$$\mathbf{S_{FS} = 2.89}$$

Thus, the conventional structural steel leaf spring is safe with the safety factor of 2.89. Since the safety factor of this system is greater than given by (Kalwaghe and Sontakke, 2014), this leaf spring is safe.

The maximum deflection of the conventional steel leaf spring can be determined as follows:

$$\delta_{max,Ls} = \frac{2\sigma_{Ls}(\mathrm{L_{eff}})^2}{3Et_{PSS}}$$ Equation 4.13

Where,

- $\delta_{max,Ls}$ is the maximum deflection of conventional steel leaf spring (m),
- σ_{Ls} is the bending stress of conventional steel leaf spring (Pa),
- L_{eff} is half of the effective length of the leaf spring (m),
- E is the Young's modulus of structural steel leaf spring (Pa), and
- t_{PSS} is the pack thickness of structural steel leaf spring (m).

Thus, taking Young's modulus of the conventional leaf spring 200 GPa from *Table 3.1*,

$$\delta_{max,Ls} = \frac{2 * 86.53 * 10^6(0.583)^2}{3 * 200 * 10^9 * 0.03}$$

$$\mathbf{\delta_{max,Ls} = 0.0032678\ m}$$

That is, the leaf spring has the deflection of 3.2678 mm.

Further the percentage of elongation can be chaked and compared with the standard value as follows:

$$\%El_{Ls} = \frac{\delta_{max,Ls}}{\mathrm{L_{eff}}}$$ Equation 4.14

Where,

- $\%El_{Ls}$ is the percentage of elongation of conventional steel leaf spring,

- $\delta_{max,Ls}$ is the maximum deflection of conventional steel leaf spring (m), and
- L_{eff} is half of the effective length of the leaf spring (m),

$$\%\, El_{Ls} = \frac{0.0032678}{0.583} = 0.56$$

$$\%\, \mathbf{El_{Ls}} = \mathbf{0.56}\%$$

As shown in *Table 3.1*, the elongation of the structural leaf spring is typically between 6 – 12 %. Thus, the elongation of the structural leaf spring is below the 6%.

As such, the weight of the conventional structural steel leaf spring can be determined from:

$$\mathrm{W_{LSS}} = \mathrm{\rho_S V_{SS} g} \qquad \text{Equation 4.15}$$

Where,

- W_{LSS} is the weight of structural steel leaf spring, (N),
- ρ_S is the density of structural steel leaf spring, (Kg/m^3),
- V_{SS} is the volume of structural steel leaf spring (m^3), and
- g is the acceleration due to gravity (m/s^2).

Moreover, the weight of the conventional structural steel leaf spring can be determined from:

$$\mathrm{W_{LSS}} = \mathrm{\rho_S L_{SS} w_{ss} t_{ss} g} \qquad \text{Equation 4.16}$$

Where,

- W_{LSS} is the weight of structural steel leaf spring, (N),
- ρ_S is the density of structural steel leaf spring, (Kg/m^3),
- L_{SS} is the length of structural steel leaf spring (m),
- w_{SS} is the width of structural steel leaf spring (m),
- t_{SS} is the thickness of structural steel leaf spring (m),
- g is the acceleration due to gravity (m/s^2).

As shown in *Table 3.1*, density of the structural steel is 7850 Kg/m^3. However, there are three leaves with different length. As shown in *Table 3.3*, length, width and thickness of the master leaf of conventional leaf spring are 0.7 m, 0.0762 m and 0.01 m, respectively. Thus, the weight of master leaf spring ($\mathrm{W_{LSSm}}$) is:

$$\mathrm{W_{LSSm}} = 7850 * 0.7 * 0.0762 * 0.01 * 9.81$$

$$\mathbf{W_{LSSm} = 41.076\ N}$$

Moreover, as shown in *Table 3.3*, length, width and thickness of the second leaf of conventional leaf spring are 0.6 m, 0.0762 m and 0.01 m, respectively. In addition, length, width and thickness of the third leaf of conventional leaf spring are 0.4 m, 0.0762 m and 0.01 m, respectively. Thus, following the same procedure, the weight of second leaf ($\mathrm{W_{LSS2}}$) and third leaf ($\mathrm{W_{LSS3}}$) of conventional leaf spring are:

$$\mathrm{W_{LSS2}} = 7850 * 0.6 * 0.0762 * 0.01 * 9.81$$

$$\mathbf{W_{LSS2} = 35.21\ N}$$

$$\mathrm{W_{LSS3}} = 7850 * 0.4 * 0.0762 * 0.01 * 9.81$$

$$\mathbf{W_{LSS3} = 23.47\ N}$$

Hence, the total weight of the conventional steel leaf spring ($\mathrm{W_{LSSt}}$) is:

$$\mathrm{W_{LSSt}} = \mathrm{W_{LSSm}} + \mathrm{W_{LSS2}} + \mathrm{W_{LSS3}}$$

$$\mathrm{W_{LSSt}} = 41.076 + 35.21 + 23.47$$

$$\mathbf{W_{LSSt} = 99.756\ N}$$

Therefore, the total weight of the current existing steel leaf spring of the Toyota Tacoma SR 2020 model is 99.756 N or 10.168 Kg. However, since the leaf springs are used for rear wheel only, there are two set of leaf spring for the vehicle. That is for right rear wheel and for left rear wheel. Thus, the total weight for both leaf spring is 199.512 N or 20.3376 Kg. Moreover, as shown in Table 3.2, the kerb weight of the vehicle is 734.82 Kg. Hence,

$$W_{LS,Per} = \frac{W_{LS,Tot}}{V_k} * 100 \qquad \text{Equation 4.17}$$

Where,

- ➢ $W_{LS,Per}$ is the weight percentage of structural steel leaf spring, (%),
- ➢ $W_{LS,Tot}$ is the weight of structural steel leaf springs, (Kg), and
- ➢ V_k is the kerb weight of vehicle, (Kg).

$$W_{LS,Per} = \frac{20.3376}{734.82} * 100$$

$$\mathbf{W_{LS,Per}} = \mathbf{2.767698}\ \%$$

Hence, the weight of leaf spring accounts for 2.77 % of the kerb weight of the vehicle.

4.2. Mono Composite Leaf Spring

As discussed, and calculated in section *4.1,* the conventional structural steel leaf spring which has a density of 7850 Kg/m^3 which resulted in the weight of 99.756 N. This value is high for light weight vehicle. For the two-leaf spring of the rear wheel the weight of the conventional structural steel leaf spring was roughly around 200 N. On each leaf spring there is about 10,178.81 N of load. Thus, the weight of the leaf spring accounts for 1% of the load on the spring. Hence, it is about to replace by mono composite leaf spring. In order to do so, four composites are selected as discussed in section *3.2.* The mono composite leaf spring is designed by considering the standard dimensions of the automobile suspension springs given in *Table 4.1*. The recommended or preferred widths are marked with '*'.

Table 4.1: Standard sizes for the automobile suspension spring (Patel, 2014)

Nominal Width (mm)	32	40*	45	50*	55	60*	65	70*	75	80	90	100	125
Eye bore diameter (mm)	19	20	22	23	25	27	28	30	32	35	38	50	55

4.2.1. Carbon Fiber Reinforced Polymer Leaf Spring

Taking the length of the leaf spring to be 0.7 m, as that of master leaf of conventional leaf spring, as shown in *Table 3.3*, and width of the leaf spring to be 0.07 m as shown in *Table 4.1*, the effective length of the CFRP leaf can be determined from:

$$2L_{eff,CF} = 2L_{1,CF} - \frac{2}{3}l \qquad \text{Equation 4.18}$$

Where,

- $2L_{eff,\mathrm{CF}}$ is the effective length of CFRP leaf spring (m),
- $L_{1,\mathrm{CF}}$ is the total length of CFRP leaf spring (m), and
- l is width of band or U – bolts (m).

$$2\mathrm{L}_{\mathrm{eff,CF}} = 2(0.7) - \frac{2}{3}(0.35)$$

$$\mathbf{2L_{eff,\mathrm{CF}} = 1.166\ m}$$

$$\mathbf{L_{eff,\mathrm{CF}} = 0.583\ m}$$

Hence, half effective length of the CFRP leaf spring is 0.583 m.

Now, it is important to obtain the minimum thickness required to bear the load applied. This can be determined by taking the initially assumed safety factor.

$$\sigma_{LCF,max} = \frac{\sigma_{CCF}}{SF_{CF,a}} \qquad \text{Equation 4.19}$$

Where,

- $\sigma_{LCF,max}$ is the maximum bending stress of CFRP leaf spring (Pa),
- σ_{CCF} is the compressive strength of CFRP (Pa), and
- $SF_{CF,a}$ is the assumed safety factor for the CFRP leaf spring.

Taking the compressive strength of the CFRP MPa, as shown in *Table 3.1*, and safety factor of 2:

$$\sigma_{LCF,max} = \frac{450 * 10^6}{2}$$

$$\boldsymbol{\sigma}_{\mathbf{LCF,max}} = \mathbf{225\ MPa}$$

Then, the initial thickness can be obtained from:

$$t_{CF} = \sqrt{\frac{6W_{ELS}\mathrm{L}_{\mathrm{eff,CF}}}{nw_{CF}\sigma_{LCF,max}}} \qquad \text{Equation 4.20}$$

Where,

- t_{CF} is the thickness of CFRP leaf spring (m),
- $\sigma_{LCF,max}$ is the maximum bending stress of CFRP leaf spring (Pa),
- $L_{eff,CF}$ is half of the effective length of CFRP leaf spring (m),
- W_{ELS} is the weight of the vehicle on eye of a single leaf spring, (N),
- n is the number of leaves of the leaf spring, and
- w_{CF} is the width of CFRP leaf spring (m).

$$t_{CF} = \sqrt{\frac{6 * 5089.4 * 0.583}{1 * 0.07 * 225 * 10^6}}$$

$$\mathbf{t_{CF} = 0.03363\ m}$$

Hence, taking the thickness of the leaf spring to be 0.04 m, bending stress of the CFRP spring can be determined as follows:

$$\sigma_{LCF} = \frac{6W_{ELS}\mathrm{L_{eff,CF}}}{nw_{CF}(t_{CF})^2} \qquad \text{Equation 4.21}$$

Where,

- σ_{LCF} is the bending stress of CFRP leaf spring (Pa),
- $L_{eff,CF}$ is half of the effective length of CFRP leaf spring (m),
- W_{ELS} is the weight of the vehicle on eye of a single leaf spring, (N),
- n is the number of leaves of the leaf spring,
- w_{CF} is the width of CFRP leaf spring (m), and
- t_{CF} is the pack thickness of CFRP leaf spring (m).

$$\sigma_{L,CF} = \frac{6 * 5089.4 * 0.583}{0.07(0.04)^2}$$

$$\mathbf{\sigma_{L,CF} = 159.0438\ MPa}$$

Thus, 159.0438 MPa of stress occurred around one eye of the CFRP leaf spring.

As shown in *Table 3.1*, the compressive strength of the CFRP leaf spring is 450 MPa, the safety factor of this system can be determined from:

$$S_{F,CF} = \frac{\sigma_{CCF}}{\sigma_{LCF}} \qquad \text{Equation 4.22}$$

Where,

- S_{FCF} is the safety factor of CFRP leaf spring,
- σ_{CCF} is the compressive strength of CFRP leaf spring (Pa),
- σ_{LCF} is the bending stress of CFRP leaf spring (Pa),

Hence,

$$S_{FCF} = \frac{450 * 10^6}{159.0438 \ * 10^6}$$

$$\mathbf{S_{FCF} = 2.829}$$

Thus, the CFRP leaf spring is safe with the safety factor of 2.829 which is greater than the initially assumed safety factor.

The maximum deflection of CFRP leaf spring can be determined as follows:

$$\delta_{max,CF} = \frac{2\sigma_{LCF}\left(\mathrm{L_{eff,CF}}\right)^2}{3E_{CF}t_{CF}} \qquad \text{Equation 4.23}$$

Where,

- $\delta_{max,CF}$ is the maximum deflection of CFRP leaf spring (m),
- σ_{LCF} is the bending stress of CFRP leaf spring (Pa),
- $L_{eff,CF}$ is half of the effective length of CFRP leaf spring (m),
- E_{CF} is the Young's modulus of CFRP leaf spring (Pa), and
- t_{CF} is the pack thickness of CFRP leaf spring (m).

Thus, taking Young's modulus of the CFRP Leaf Spring 75 GPa from *Table 3.1*,

$$\delta_{max,CF} = \frac{2 * 159.0438 * 10^6(0.583)^2}{3 * 75 * 10^9 * 0.04}$$

$$\boldsymbol{\delta_{max,CF} = 0.01203\ m}$$

That is, the CFRP leaf spring has the deflection of 12.03 mm.

Further the percentage of elongation can be checked and compared with the standard value as follows:

$$\%El_{CF} = \frac{\delta_{max,CF}}{L_{eff,CF}} * 100 \qquad \text{Equation 4.24}$$

Where,

- $\%El_{CF}$ is the percentage of elongation of CFRP leaf spring,
- $\delta_{max,CF}$ is the maximum deflection of CFRP leaf spring (m), and
- $L_{eff,CF}$ is half of the effective length of the leaf spring (m),

$$\%\ El_{CF} = \frac{0.01203}{0.583} * 100$$

$$\%\ \mathbf{El_{CF}} = \mathbf{2.06}\ \%$$

As shown in *Table 3.1*, the elongation of the CFRP leaf spring is typically 2.5 %. Thus, the elongation of the CFRP leaf spring is below the 2.06%.

Furthermore, in order to determine the weight saved by this material, the weight of the CFRP leaf spring must be determined as follows:

$$W_{LCF} = \rho_{CF} V_{CF} g \qquad \text{Equation 4.25}$$

Where,

- W_{LCF} is the weight of CFRP leaf spring, (N),
- ρ_{CF} is the density of CFRP leaf spring, (Kg/m^3),
- V_{CF} is the volume of CFRP leaf spring (m^3), and
- g is the acceleration due to gravity (m/s^2).

Moreover, the weight can be determined as follows:

$$W_{LCF} = \rho_{CF} L_{CF} w_{CF} t_{CF} g \qquad \text{Equation 4.26}$$

Where,

- W_{LCF} is the weight of CFRP leaf spring, (N),
- ρ_{CF} is the density of CFRP leaf spring, (Kg/m^3),
- L_{CF} is the length of CFRP leaf spring (m),
- w_{CF} is the width of CFRP leaf spring (m),
- t_{CF} is the thickness of CFRP leaf spring (m),
- g is the acceleration due to gravity (m/s^2).

Thus, taking the density of the CFRP to be 2000 Kg/m^3, as shown in *Table 3.1*, the weight of the CFRP leaf spring is:

$$\mathrm{W_{LCF}} = 2100 * 0.7 * 0.07 * 0.04 * 9.81$$

$$\mathbf{W_{LCF} = 40.38\ N}$$

That is, for one wheel leaf spring, the CFRP leaf spring weigh 40.38 N or **4.116 Kg**. Thus, for both wheel leaf spring, the CFRP leaf spring weigh 80.76 N or **8.232 Kg**.

Hence, compared to the conventional leaf spring, the weight reduced or saved, considering one wheel leaf spring, can be determined by:

$$\mathrm{W_{sCF}} = \mathrm{W_{LSSt}} - \mathrm{W_{LCF}}$$

$$\mathrm{W_{sCF}} = 99.756 - 40.38$$

$$\mathbf{W_{sCF} = 59.376\ N}$$

Hence, if both rear wheel leaf spring is considered, 118.752 N or 12.1 Kg of weight was saved.

Furthermore, in percentage:

$$\mathrm{W_{sCF}} = \frac{\mathrm{W_{LSSt}} - \mathrm{W_{LCF}}}{\mathrm{W_{LSSt}}} * 100$$

$$\mathrm{W_{sCF}} = \frac{99.756 - 40.38}{99.756} * 100$$

$$\mathbf{W_{sCF} = 59.52\%}$$

Thus, compared to the Kerb weight of the vehicle, the weight reduced can be determined by:

$$W_{sCF} = \frac{V_{k,i} - V_{k,n}}{V_{k,i}} * 100$$ Equation 4.27

$$W_{sCF} = \frac{V_{k,i} - (V_{k,i} - W_{LS,Tot} + 2 * W_{LCF})}{V_{k,i}} * 100$$ Equation 4.28

Where,

- W_{sCF} is the weight percentage of CFRP leaf spring, (%),
- $W_{LS,Tot}$ is the weight of structural steel leaf springs, (Kg),
- W_{LCF} is the weight of CFRP leaf springs, (Kg), and
- $V_{k,i}$ and $V_{k,n}$ is the kerb weight of vehicle, (Kg).

$$W_{sCF} = \frac{734.82 - (734.82 - 20.3376 + 2 * 4.116)}{734.82} * 100$$

$$\mathbf{W_{sCF} = 1.65\ \%}$$

Hence, 1.65 % of kerb weight of the vehicle can be saved by using CFRP leaf spring. According to (Robinson et al., 2019), a 10% weight reduction generates a 6% improvement in fuel economy for light vehicles. Thus, 1.65 % weight reduction will generate:

$$\text{Fuel economy}_{CF} = \frac{1.65\ \%\ \text{weight saved} * 6\%\ \text{of fuel economy}}{10\ \%\ \text{weight saved}}$$

$$\text{Fuel economy}_{CF} = \frac{0.0165 * 0.06}{0.1}$$

$$\mathbf{Fuel\ economy_{CF} = 0.99\%}$$

That is, by replacing conventional steel leaf spring with CFRP leaf spring, the fuel economy of Toyota Tacoma SR 2020 model can be improved by 0.99%. Currently, as shown in *Table 3.2*, Toyota Tacoma SR 2020 model has fuel economy of 8.503 Km/Liter. Hence, the new fuel economy is:

$$\text{New Fuel economy}_{CF} = \text{Old Fuel economy} + (\text{Old Fuel economy} * \text{Fuel economy}_{CF})$$

$$\text{New Fuel economy}_{CF} = 8.503 + (8.503 * 0.0099)$$

$$\text{New Fuel economy}_{CF} = \mathbf{8.587\ Km/Liter}$$

Let consider the vehicle travels 50 Km daily, that is 18,250 Km annually. Hence, the fuel saved annually can be calculated as:

$$\text{Fuel saved}_{CF} = \left(\frac{\text{Distance travelled}}{\text{Old Fuel economy}}\right) - \left(\frac{\text{Distance travelled}}{\text{New Fuel economy}_{CF}}\right)$$

$$\text{Fuel saved}_{CF} = \left(\frac{18250}{8.503}\right) - \left(\frac{18250}{8.587}\right)$$

$$\mathbf{Fuel\ saved_{CF} = 21\ Liter/year}$$

That is, by replacing conventional steel leaf spring with CFRP leaf spring, 21 Liter of fuel is saved per year. Moreover, the expense saved can be calculated as:

$$\text{Expense saved}_{CF} = \text{Fuel saved}_{CF} * Price\ of\ fuel$$

$$\text{Expense saved}_{CF} = \left(21\frac{Liter}{year}\right) * \left(78\frac{Birr}{Liter}\right)$$

$$\mathbf{Expense\ saved_{CF} = 1638\frac{Birr}{Year}}$$

That is, by replacing conventional steel leaf spring with CFRP leaf spring, 1,638 Brr is saved per year.

Similarly, after performing detailed calculations, results shown in *Table 4.2* are obtained. As such, using E – Glass leaf spring can save 51.81% of weight of leaf spring. Thus, by replacing conventional steel leaf spring with E – Glass leaf spring, 18.27 Liter of fuel estimated to be 1,425 Birr can be saved per year. In addition, using Technora H leaf spring can save 73.21% of weight of leaf spring. Thus, by replacing conventional steel leaf spring with Technora H leaf spring, 44.25 Liter of fuel estimated to be 3451.5 Birr can be saved per year. Moreover, using BFRP leaf spring can save 66.95% of weight of leaf spring. Thus, by replacing conventional steel leaf spring with BFRP leaf spring, 23.62 Liter of fuel estimated to be 1842 Birr can be saved per year.

Table 4.2: Summary of Mono Composite Leaf Spring results

S.No.	Parameter	CFRP	E-Glass	Technora H	BFRP
1	Maximum Deflection (mm)	12.03	12.46	12.89	9.47
2	Elongation (%)	2.06	2.13	2.21	1.893
3	Safety Factor	2.829	3.77	3.14	3.67
4	Total weight (N)	80.76	96.14	53.44	65.92
5	Saved Weight (N)	118.752	103.36	146.06	133.58
6	Saved Weight (%)	59.52	51.81	73.21	66.95
7	Fuel Economy (Km/L)	8.587	8.576	8.682	8.5976
8	Fuel Saved (L/year)	21	18.27	44.25	23.616
9	Expense Saved (ETB/year)	1638	1425	3451.5	1842.05

4.3. Vibration Analysis

An object vibrates when it repeatedly moves in an equilibrium state. Period, amplitude, and frequency are its defining characteristics. It is usually brought on by outside factors like the wind, the state of the roads, or vibrations from engines. Therefore, in the absence of outside forces, a system's natural frequency of oscillation is provided by:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$ Equation 4.29

Where

- f_n is the natural frequency of the system,
- k is the stiffness of the system, and
- m is the mass of the system.

Three fundamental vibrational types exist. These three types of vibration are torsional, transverse, and longitudinal. Particles in longitudinal vibration travel in a direction parallel to the wave's propagation direction. In contrast, particles in transverse vibration travel in a path perpendicular to the wave's propagation direction. Additionally, there is twisting motion around the object's axis during torsional vibration.

Vibration in relation to leaf springs is the term used to describe the oscillations of the spring under dynamic stresses. Understanding the dynamic behavior of leaf springs requires a thorough understanding of vibration analysis. It aids in evaluating possible failure modes, fatigue life, and ride quality. A leaf spring can be conceptualized as a simply supported beam that is subject to bending vibrations for a basic analysis. As such, for a cantilever beam, the transverse vibration equation is:

$$EI\frac{d^4y}{dx^4} + \rho A\frac{d^2y}{dt^2} = 0 \qquad \text{Equation 4.30}$$

Where:

- E is Young's modulus,
- I is the second moment of area,
- ρ is the density,
- A is the cross-sectional area,
- y is the displacement.

Because steel has a higher mass and less stiffness than composite leaf springs, steel leaf springs usually have a lower natural frequency. However, since there are various factors involved in the determination of vibration characteristics and analysis, usually using analytical method is inaccurate. As such, FEA is used for vibration analysis.

CHAPTER FIVE

5. MODELING OF LEAF SPRINGS

5.1. CAD Modeling

For both the conventional steel leaf spring model and mono composite leaf spring model, SolidWorks software is used. Since the conventional steel leaf spring and mono composite leaf spring have different dimensions, independent models are created. The detail process used and model of each leaf spring are discussed in the following sections.

5.1.1. CAD Modeling of Conventional Steel Leaf Spring

In order to create CAD model of conventional steel leaf spring, various dimensions such as number of leaves, length, width and thickness of each leaf, eye diameter, radius of curvature, dimensions of the connectors are required. The summary of the dimensions required are given in *Table 5.1*.

Table 5.1: Summary of the dimensions of conventional steel leaf spring

<table>
<tr><td>S.No.</td><td>Parameter</td><td>Length (m)</td><td>Width (m)</td><td>Thickness (m)</td></tr>
<tr><td>1</td><td>Master leaf (1st Leaf)</td><td>0.7</td><td>0.0762</td><td>0.01</td></tr>
<tr><td>2</td><td>2nd leaf</td><td>0.6</td><td>0.0762</td><td>0.01</td></tr>
<tr><td>3</td><td>3rd leaf</td><td>0.4</td><td>0.0762</td><td>0.01</td></tr>
<tr><td>4</td><td>Connector Base</td><td>0.13</td><td>0.05</td><td>0.01</td></tr>
<tr><td>5</td><td>Pin</td><td>0.08</td><td>0.011</td><td>0.01</td></tr>
<tr><td></td><td></td><td colspan="2">Length (m)</td><td>Diameter (m)</td></tr>
<tr><td>6</td><td>Bolt</td><td colspan="2">0.08</td><td>0.02</td></tr>
<tr><td>7</td><td>Middle Nut</td><td colspan="2">0.01</td><td>0.02</td></tr>
<tr><td>8</td><td>Pin Nut</td><td colspan="2">0.01</td><td>0.006</td></tr>
<tr><td>9</td><td>Eye diameter (m)</td><td colspan="3">0.02</td></tr>
<tr><td>10</td><td>Radius of curvature (m)</td><td colspan="3">1</td></tr>
</table>

Hence, based on the dimensions given in *Table 5.1*, the 3D CAD model of each leaf, created using SolidWorks software, are given in *Appendix 1* up to *Appendix 9*. As such, there are three basic geometries on the master leaf. These are, the leaf, the eye which is used to connect the leaf with the chassis, and the bolt hole which is used to connect the master leaf with another leaf. The master leaf rest on the second leaf and it is connected with the help of the connectors.

In addition, there are two basic geometries on the second leaf. These are, the leaf, and the bolt hole which is used to connect the secondary leaf with the master leaf and the third leaf. The second leaf rest on the third leaf and it is connected to both the master leaf and third leaf with the help of the connectors.

Moreover, there are two basic geometries on the third leaf. These are, the leaf, and the bolt hole which is used to connect the third leaf with the second leaf and base of the connector. The third leaf rest on the base of the connector and it is connected to the second leaf with the help of the connectors.

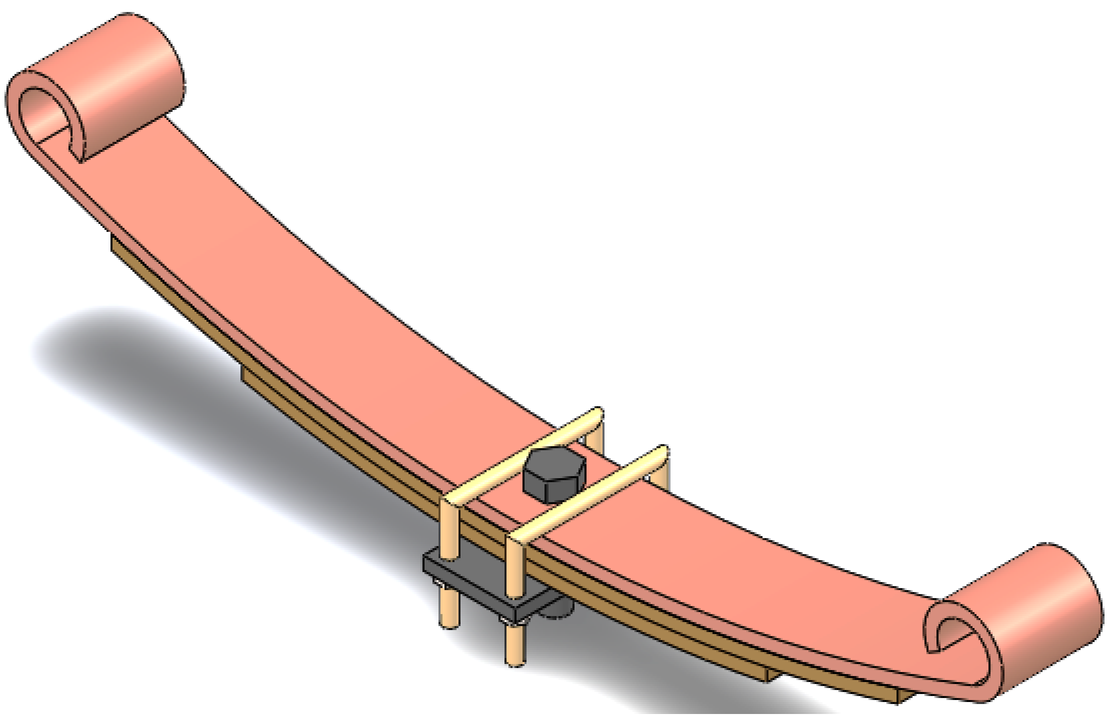


Figure 5.1: SolidWorks model Assembly view of conventional steel leaf spring

Furthermore, connectors consist of base of the connector, bolt, pins and nuts. The base of the connector holds the third leaf and consists of five holes for pins and bolts. The bolt passes through all the leaf and the base of the connector, and it is locked by mid nuts. The pins hold the leaf and it is locked by four small nuts.

Finally, the assembly of the parts is given in *Figure 5.1*. The assembly consists of master leaf, the second leaf, the third leaf, and the connectors.

5.1.2. CAD Modeling of Mono Composite Leaf Spring Model

In order to create CAD model of mono composite leaf spring, various dimensions such as, length, width and thickness of leaf, eye diameter, and radius of curvature are required. As shown in section *4.2.1* up to ***Error! Reference source not found.***, the same dimensions are considered for all types of composites considered. The summary of the dimensions required are given in *Table 5.2*.

Table 5.2: Summary of the dimensions of mono composite leaf spring

S.No.	Parameter	Length (m)	Width (m)	Thickness (m)
1	Leaf	0.7	0.07	0.04
2	Eye diameter (m)			0.04
3	Radius of curvature (m)			1

Hence, based on the dimensions given in *Table 5.2*, the 3D CAD model of the leaf, created using SolidWorks software, is given in *Figure 5.2*.

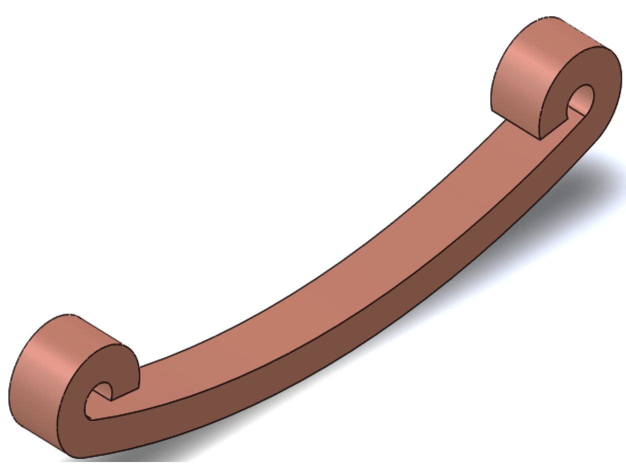


Figure 5.2: SolidWorks model snap view of mono composite leaf spring

5.2. FEA of Leaf Springs

5.2.1. FEA of Conventional Steel Leaf Springs

After the assembly of the leaf spring is created from the individual component of the conventional steel leaf spring, analysis begins with selecting the module from ANSYS workbench. As such ANSYS static structural, modal, and random vibration modules are selected, as shown in *Figure 5.3*. These modules are used for structural analysis, fatigue analysis, natural frequency analysis, and vibration analysis. And each steps used are discussed below starting with the geometry.

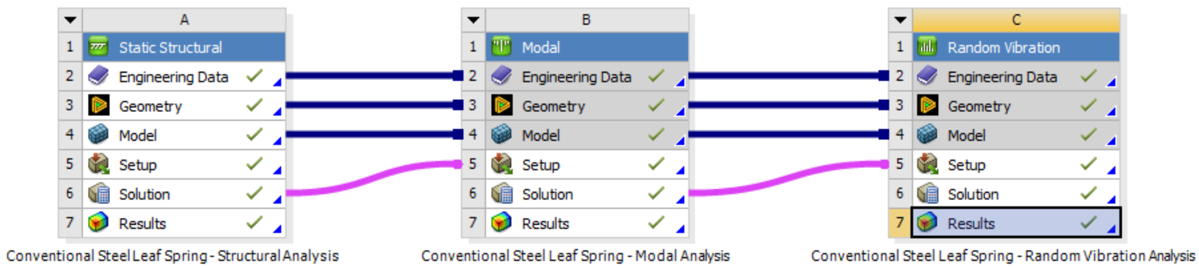


Figure 5.3: Basic procedures in ANSYS Workbench

For the conventional leaf spring, structural steel is selected from ANSYS engineering material library. The library includes material properties such as density, Young's modulus, Poisson's ratio and so on. Moreover, the assembly of conventional steel leaf spring created in SolidWorks is imported to ANSYS geometry module. Then, the geometry is opened in ANSYS Mechanical for further analysis. Furthermore, for conventional steel leaf spring, meshing is performed in ANSYS Mechanical using face sizing to obtain fine the meshing, as shown in *Figure 5.4*. As such, with 0.005m element size, the mesh generates 105330 nodes and 40941 elements.

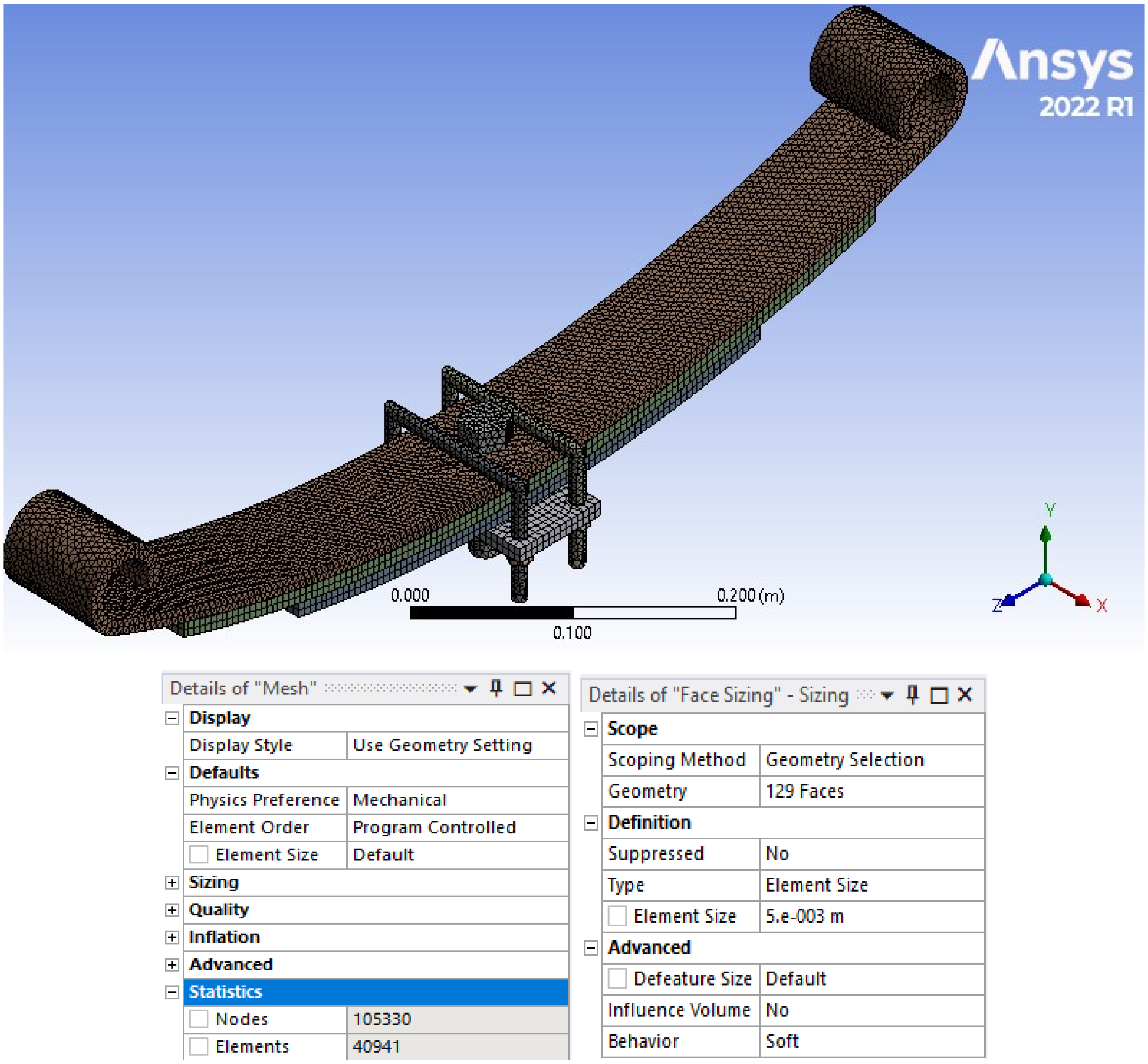


Figure 5.4: Meshing in ANSYS Mechanical for conventional steel leaf spring

In addition, conventional steel leaf springs are fixed at the eye of the spring and portion of the vehicle load, which is 10179.91 N is distributed all over the leaf spring. Thus, constraint and load are applied, as shown in *Figure 5.5*.

Finally, after analysis is completed, ANSYS mechanical can generate various results upon request. For this particular model, total deformation, strain, stress and strain energy are considered for the solution. Moreover, natural frequency of the model is generated by considering six modes of analysis. Furthermore, based on the modal analysis vibration analysis is performed.

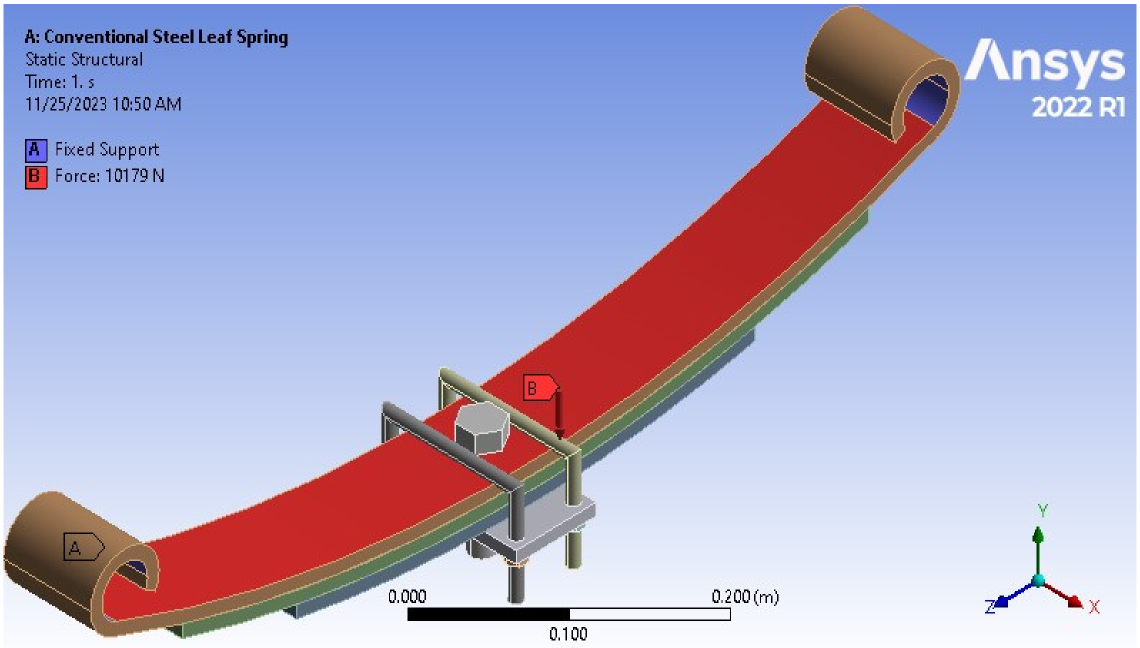


Figure 5.5: The load and the displacement on conventional steel leaf spring

5.2.2. FEA of Mono Composite Leaf Springs

After the geometry of mono composite leaf spring is created in SolidWorks, FEA of these component begins with selecting the module from ANSYS workbench. As such ANSYS Static structure, Modal, and Random Vibration are selected, as shown in *Figure 5.6*. Here, since the same geometry is created for all of the four composites, standalone geometry module is selected from ANSYS workbench and shared for all of the MCLS model.

Moreover, new materials are crreated in ANSYS engineering material library and required property is inserted across the property rows. As such four new material for CFRP, E – Glass, Technora H and BFRP are created. The library includes material properties such as density, Young’s modulus, Poisson’s ratio and so on.

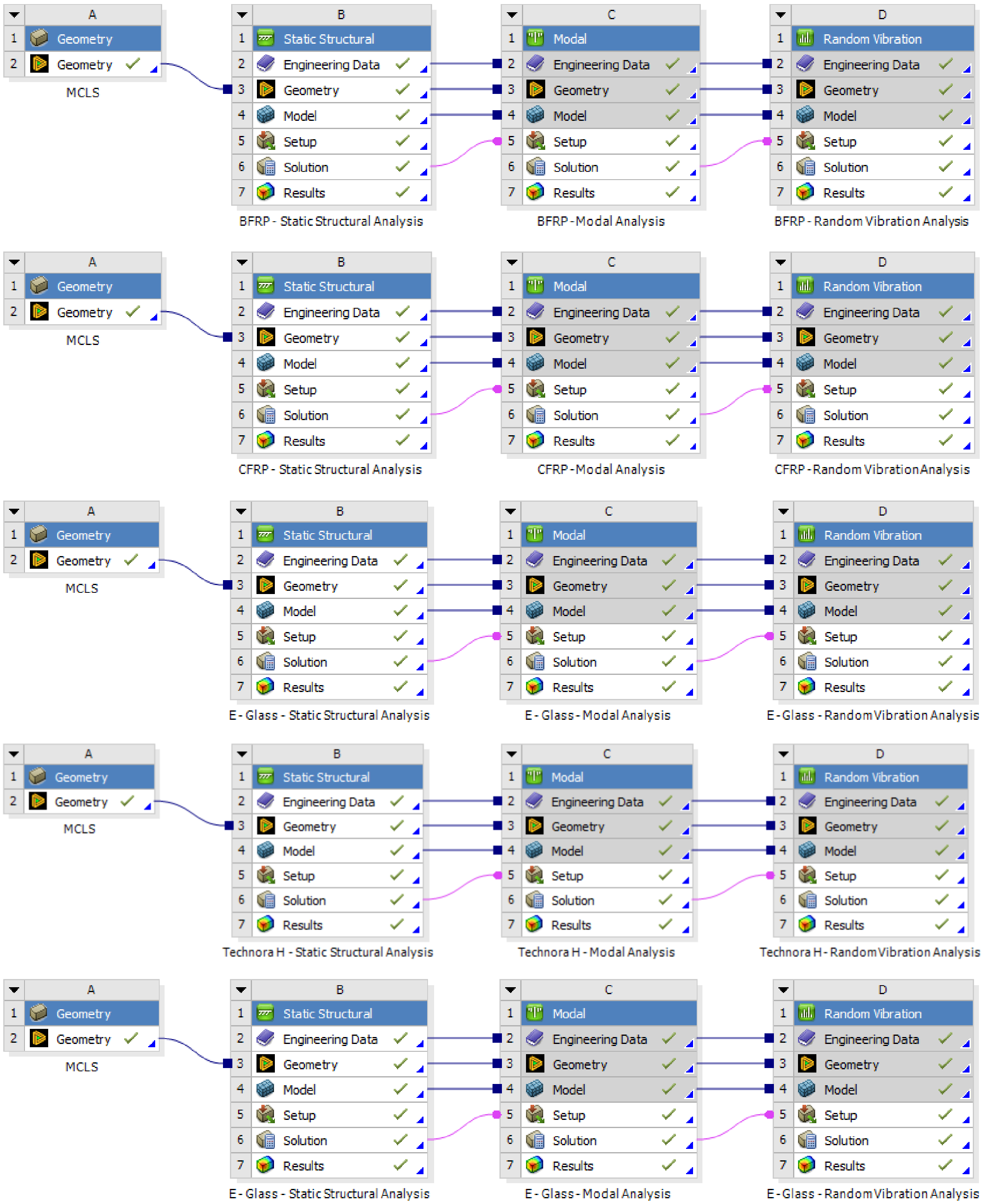


Figure 5.6: Basic procedures for FEA of MCLS in ANSYS Workbench

Moreover, MCLS model created in SolidWorks is imported to ANSYS geometry module. The imported geometry is shown in ANSYS Design modeler. Furthermore, for MCLS, meshing is performed in ANSYS Mechanical using face sizing to obtain fine the meshing, as shown in *Figure 5.7*. As such, with 0.006m element size, the mesh generates 66652 nodes and 37782 elements.

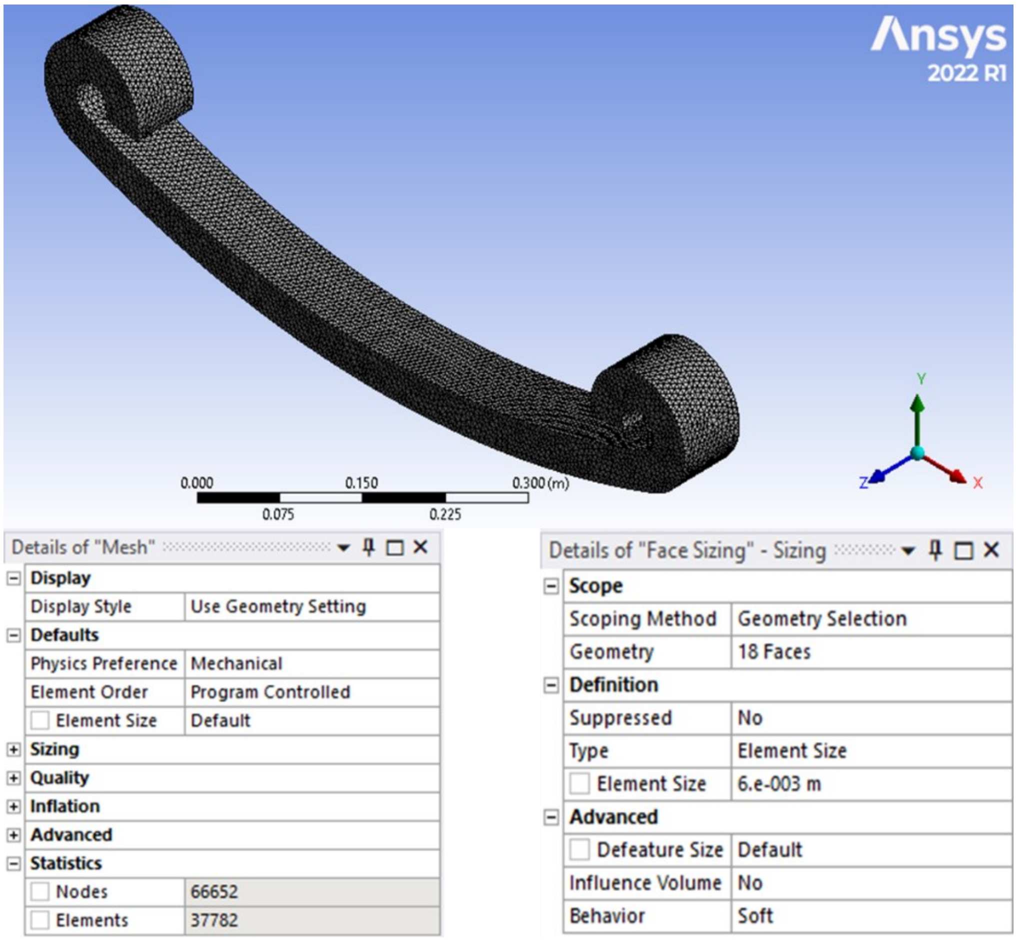


Figure 5.7: Meshing in ANSYS Mechanical for MCLS

MCLS are fixed at the eye of the spring and portion of the vehicle load, which is 10179.91 N is distributed all over the leaf spring. Thus, constraint and load are applied, as shown in *Figure 5.8*.

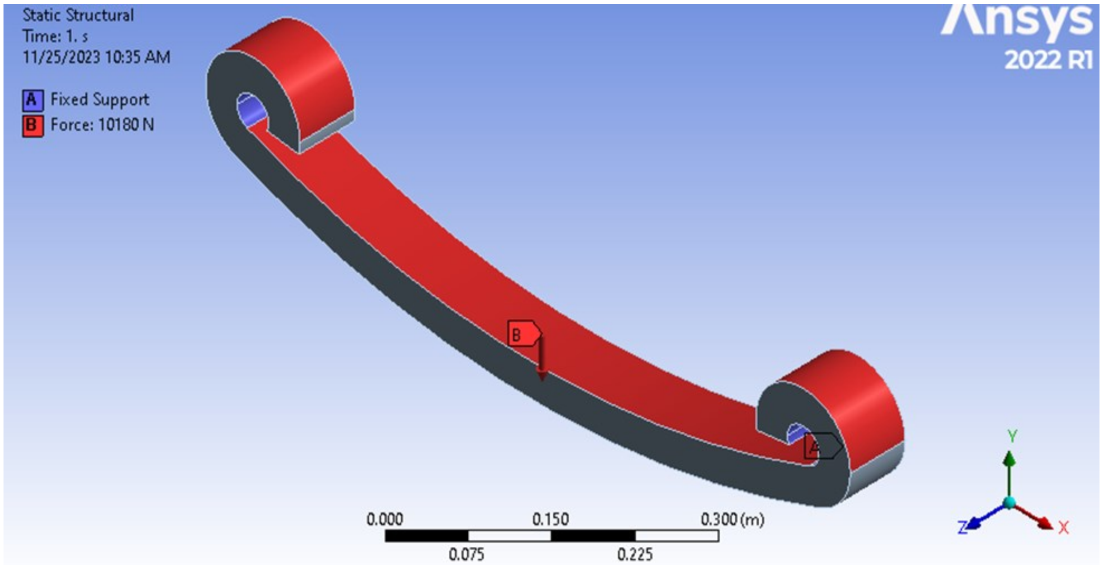


Figure 5.8: The load and the displacement on MCLS

Finally, after analysis is completed, total deformation, strain, stress and strain energy are considered for the solution. Moreover, natural frequency of the model is generated by considering six modes of analysis. Furthermore, based on the modal analysis vibration analysis is performed.

CHAPTER SIX

6. RESULT AND DISCUSSION

With the purpose of reducing the vehicle weight and improve its fuel economy, modeling and FEA of a mono composite leaf spring for lightweight vehicle is performed. The model is designed based on the design specifications acquired from Toyota Tacoma SR 2020 model. This is done by considering properties of several composite materials such as CFRP, E – Glass, Technora H and BFRP, and comparing it with the conventional steel leaf spring. Hence, the results obtained both from conceptual design and FEA are discussed below.

6.1. Weight of the Leaf Springs

To determine the fuel economy of MCLS, the analysis started with the determination of weight of MCLS. In addition, the weight of conventional steel leaf spring is compared to that of MCLS. Moreover, based on the weight saved, the fuel economy of the MCLS is calculated.

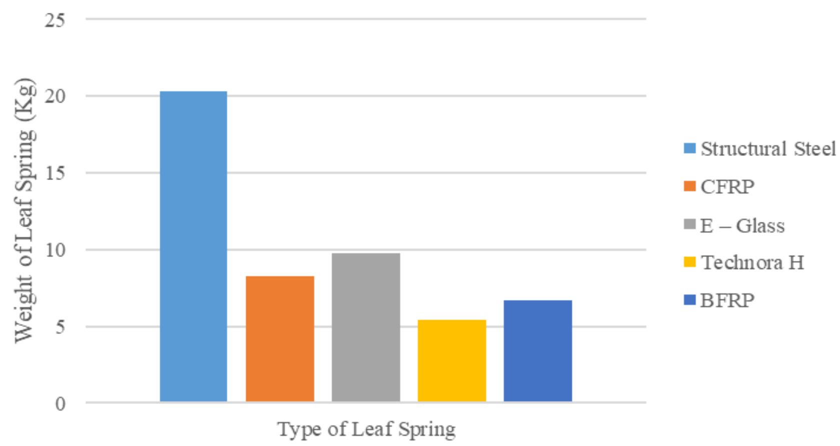


Figure 6.1: Comparison of weight of conventional steel leaf spring with MCLS

Figure 6.1 shows the weight of different types of leaf springs, including conventional steel, CFRP, E-glass, Technora H, and BFRP. As can be seen from the graph, Technora H leaf springs are the lightest with 5.44 kg, followed by BFRP, CFRP and E-glass leaf springs. Conventional steel leaf springs are the heaviest with 20.36 kg. Thus, the weight savings of Technora H leaf springs over conventional steel leaf springs is significant, at up to 73%. This is because Technora H is a very strong and lightweight material. BFRP, CFRP and E-glass leaf springs also offer significant weight savings over conventional steel leaf springs, but the weight savings are not as great as with Technora H leaf springs.

6.2. Fuel Economy of the Leaf Springs

Figure 6.2 shows the fuel economy of different types of leaf springs, including conventional steel, CFRP, E-glass, Technora H, and BFRP. As can be seen from the graph, all of the alternative leaf springs provide better fuel economy than the conventional steel leaf spring. In addition, Technora H offers the best fuel economy at 8.68 km/liter. BFRP and CFRP are also good choices with 8.59 and 8.58 km/liter respectively. E-Glass performs the least good among them with 8.57 km/liter.

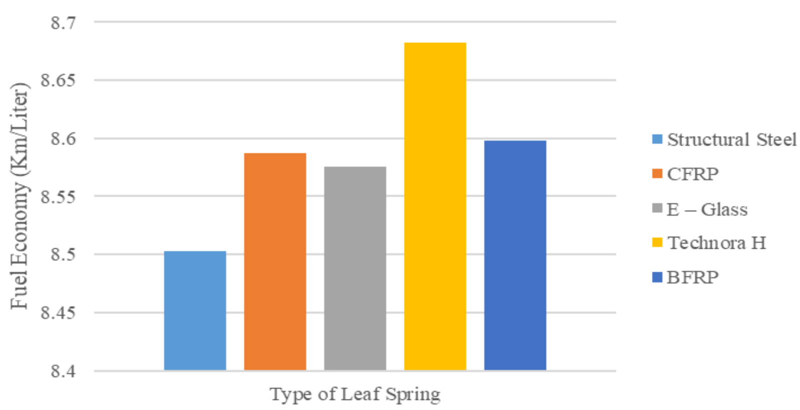


Figure 6.2: Comparison of fuel economy of vehicle with steel leaf spring and MCLS

Moreover, the fuel saved per year by replacing conventional steel leaf spring with Technora H is the largest, at 44 liters per year. BFRP and CFRP leaf springs also offer significant fuel savings, at 23 and 21 liters per year respectively. E - Glass leaf springs perform the least good among them with 18 liters per year. The reason for this is that alternative leaf springs are lighter than conventional steel leaf springs.

Furthermore, the expense saved per year by replacing conventional steel leaf spring with Technora H is the largest, with 3451 Birr per year. BFRP and CFRP leaf springs also offer significant expense savings, with 1842 and 1638 Birr per year respectively. E - Glass leaf springs perform the least good among them with 1425 Birr per year.

6.3. Mechanical Properties of the Leaf Springs

Total deformation, equivalent strain, and equivalent stresses of conventional steel leaf spring, CFRP, E – Glass, BFRP, and Technora H leaf springs are shown in *Figure 6.3*, *Figure 6.4*, *Figure 6.5*, *Figure 6.6*, and *Figure 6.7*, respectively.

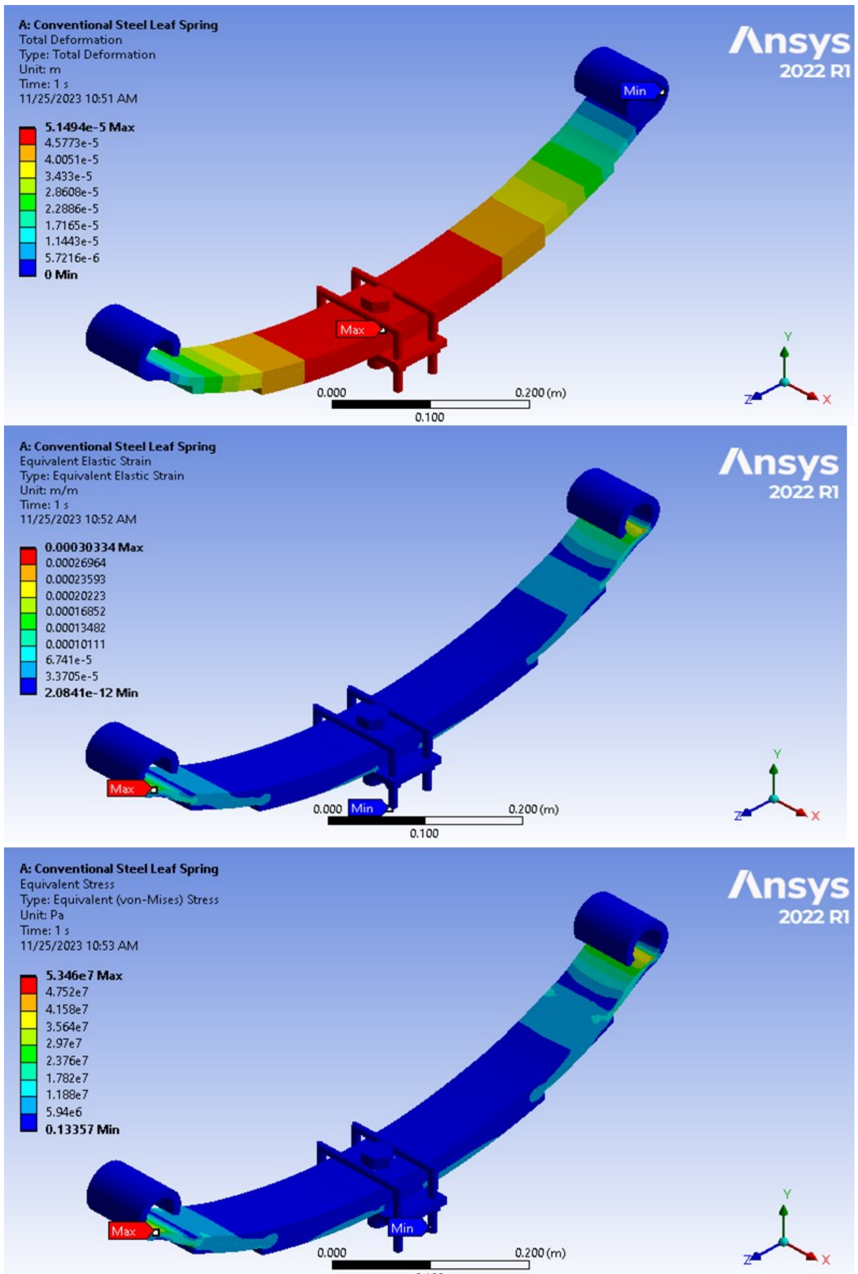


Figure 6.3: ANSYS structural analysis result for Conventional steel leaf spring

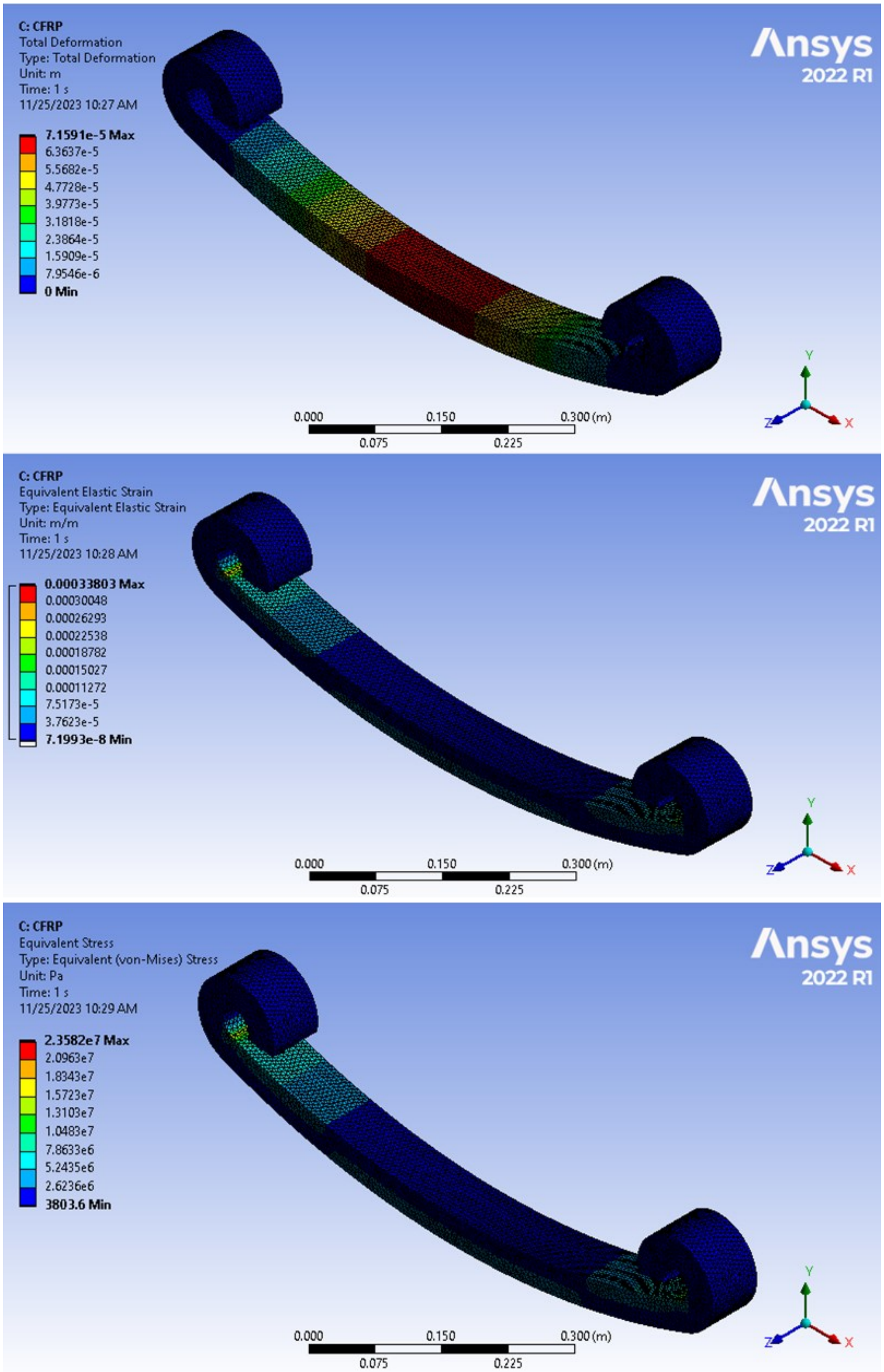


Figure 6.4: ANSYS structural analysis result for CFRP leaf spring

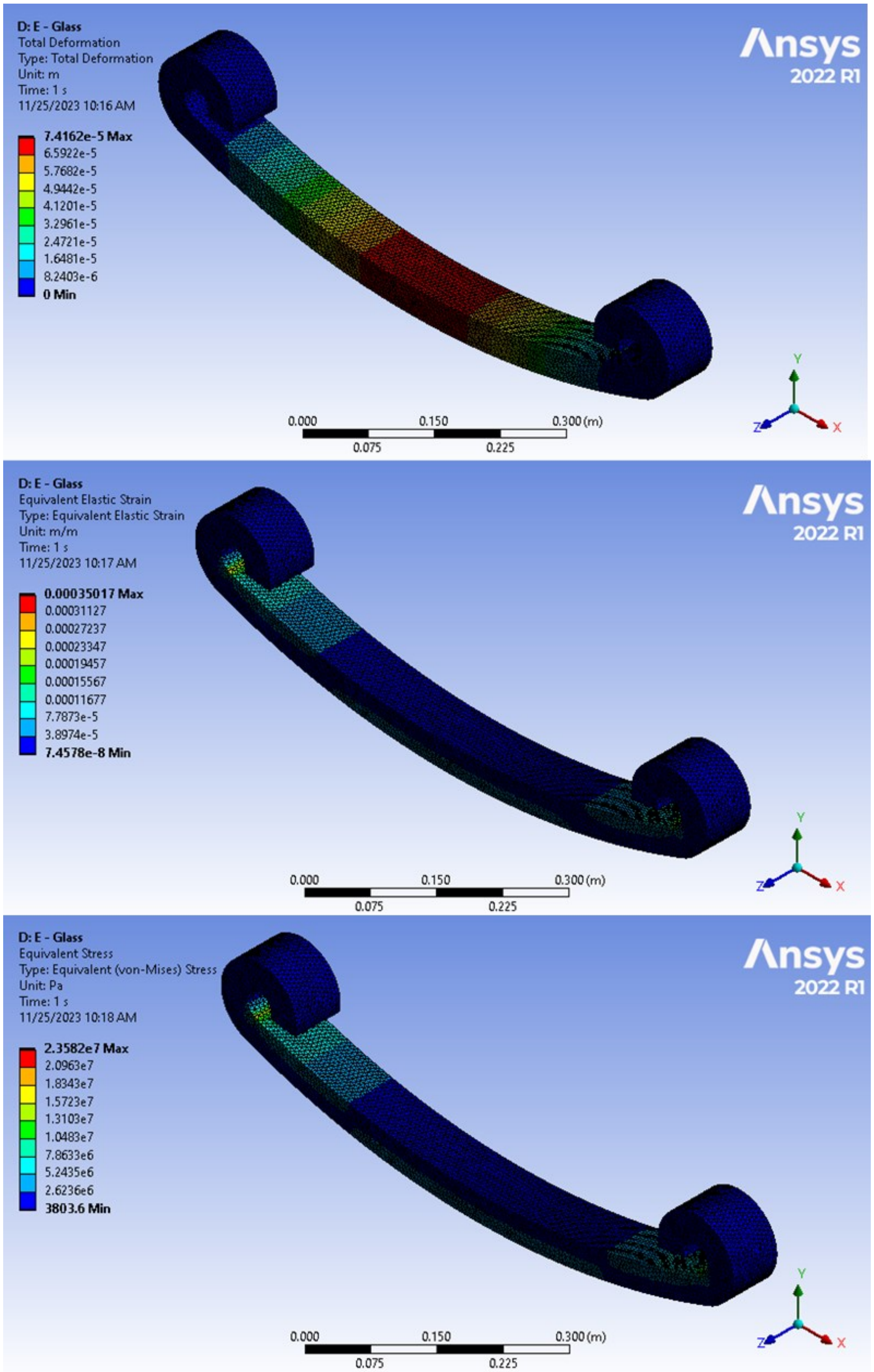


Figure 6.5: ANSYS structural analysis result for E – Glass leaf spring

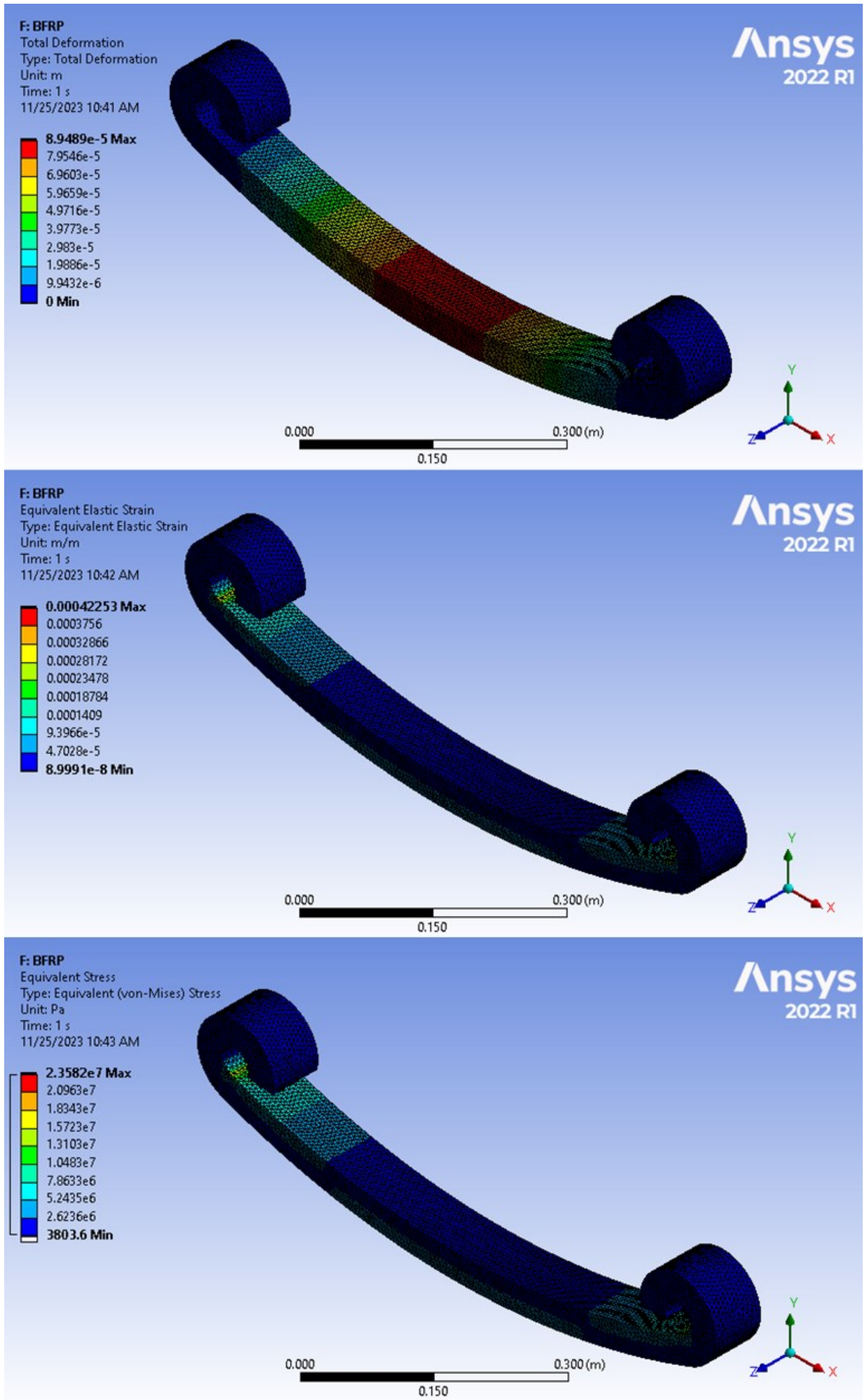


Figure 6.6: ANSYS structural analysis result for BFRP leaf spring

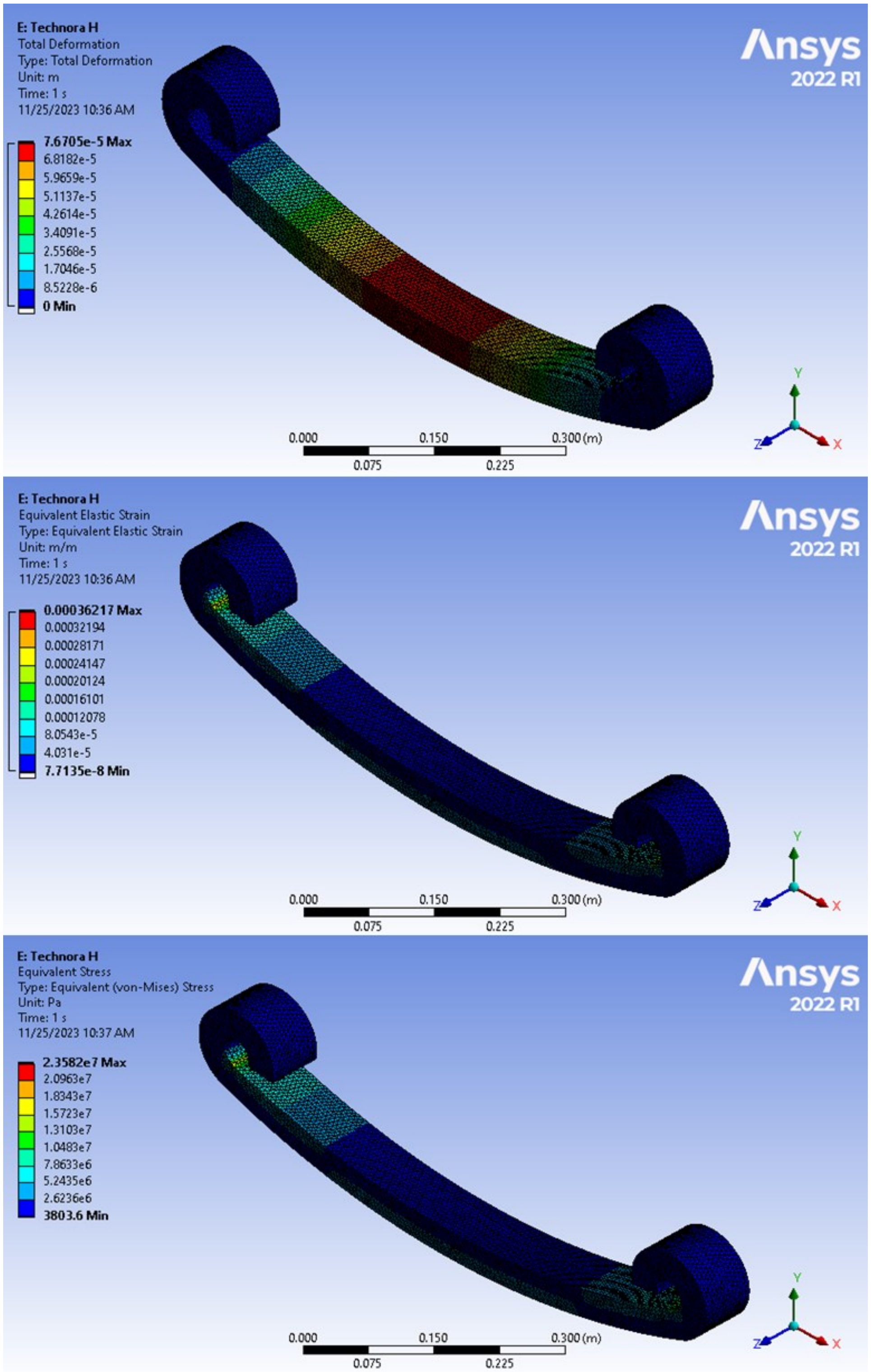


Figure 6.7: ANSYS structural analysis result for Technora H leaf spring

The total deformation of the conventional steel leaf spring, as shown in *Figure 6.3* and *Table 6.2*, is 0.05149 mm. Whereas, as shown in *Figure 6.4*, *Figure 6.5*, *Figure 6.7*, and *Figure 6.6*, the total deformation of all the alternative leaf spring are higher than the conventional leaf spring. CFRP, E – Glass, Technora H and BFRP have 0.07159 mm, 0.07416 mm, 0.07671 mm and 0.08949 mm, respectively. That is, BFRP have high deformation.

Similarly, the maximum equivalent elastic strain of the conventional steel leaf spring, as shown in *Figure 6.3* and *Table 6.2*, is 0.30334 mm per meter of the length. Whereas, as shown in *Figure 6.4*, *Figure 6.5*, *Figure 6.7*, and *Figure 6.6*, the maximum equivalent elastic strain of all the alternative leaf springs is higher than the conventional leaf spring. CFRP, E – Glass, Technora H and BFRP have 0.30338, 0.35017, 0.36217 and 0.42253 per meter of the length respectively. That is, BFRP have high equivalent elastic strain.

Moreover, the maximum equivalent elastic stress of the conventional steel leaf spring, as shown in *Figure 6.3* and *Table 6.2*, is 53.46 MPa. Whereas, *Figure 6.4*, *Figure 6.5*, *Figure 6.7*, and *Figure 6.6,* the maximum equivalent elastic stress of all the alternative leaf springs is lower than the conventional leaf spring with 23.58 MPa.

Table 6.1: Comparison of weight and fuel economy of Conventional steel leaf spring with MCLS

S.No.	Type of Leaf Spring	Weight of Leaf Spring (Kg)	Kerb Weight of Vehicle (Kg)	Fuel Economy (Km/Liter)	Weight Saved (Kg)	Fuel saved (Liter/Year)	Expense saved (Birr/Year)
1	Structural Steel	20.3376	734.82	8.503	-	-	-
2	CFRP	8.232	722.71	8.587	12.11	21	1,638
3	E – Glass	9.8	724.28	8.576	10.54	18.27	1,425
4	Technora H	5.45	719.93	8.682	14.89	44.25	3,451.5
5	BFRP	6.72	721.20	8.5976	13.62	23.616	1,842.05

Table 6.2: Comparison of FEA of Conventional steel leaf spring with MCLS

S.No.	Type of Leaf Spring	Deformation (mm)		Strain (mm/m)		Stress (Pa)		Strain energy (J)	
		Min	Max	Min	Max	Min	Max	Min	Max
1	Structural Steel	0	0.05149	$2.0841*10^{-9}$	0.30334	$1.3*10^{-1}$	$5.346*10^{7}$	$3.659*10^{-21}$	$1.0902*10^{-4}$
2	CFRP	0	0.07159	$7.1993*10^{-5}$	0.30338	$3.803*10^{3}$	$2.358*10^{7}$	$2.821*10^{-12}$	$8.7286*10^{-5}$
3	E – Glass	0	0.07416	$7.4578*10^{-5}$	0.35017	$3.803*10^{3}$	$2.358*10^{7}$	$2.922*10^{-12}$	$9.0421*10^{-5}$
4	Technora H	0	0.07671	$7.7135*10^{-5}$	0.36217	$3.803*10^{3}$	$2.358*10^{7}$	$3.022*10^{-12}$	$9.3521*10^{-5}$
5	BFRP	0	0.08949	$8.9991*10^{-5}$	0.42253	$3.803*10^{3}$	$2.358*10^{7}$	$3.526*10^{-12}$	$1.0911*10^{-4}$

6.4. Vibration Analysis

Vibration analysis is performed to determine the capabilities of various leaf spring models vibration isolation and reduced stress on the suspension system. As such, two ANSYS workbench modules are used. These are, modal and Random Vibration. Transverse vibration's natural frequency is obtained from Modal analysis, as shown in *Figure 6.8* to *Figure 6.12*. Whereas, amplitude of the vibration is obtained from Random Vibration analysis, as shown in *Figure 6.13* to *Figure 6.17*.

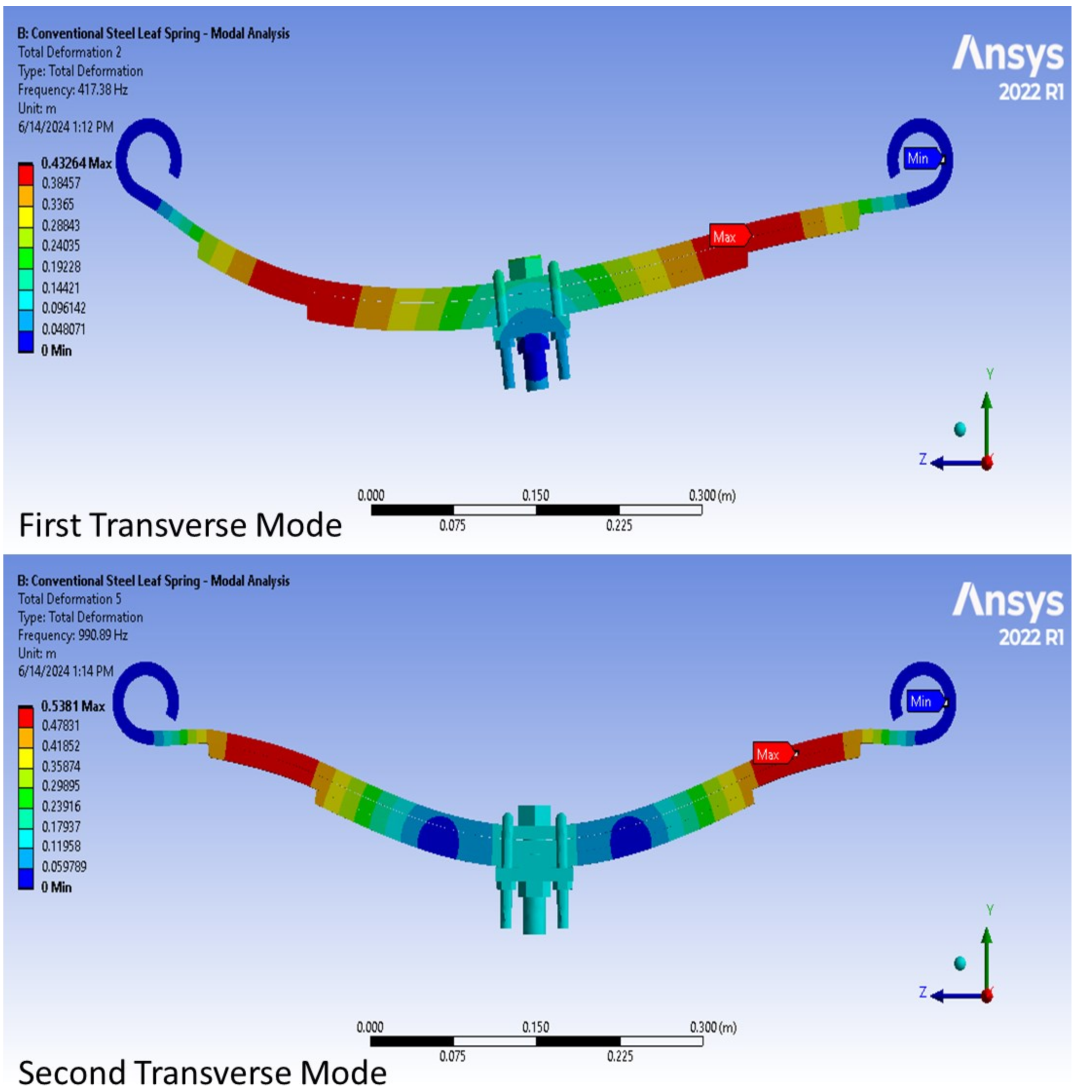


Figure 6.8: Transverse natural frequency for Conventional Leaf Spring

Figure 6.8 shows the modal analysis of conventional steel leaf spring. As such, the natural frequency for the first mode of transverse vibration is 417.38 Hz. Whereas, the natural frequency for the second mode of transverse vibration is 990.89 Hz. At the first mode of the transverse vibration, the maximum deformation is 0.43264 m. Whereas, At the second mode of the transverse vibration, the maximum deformation is 0.5381 m.

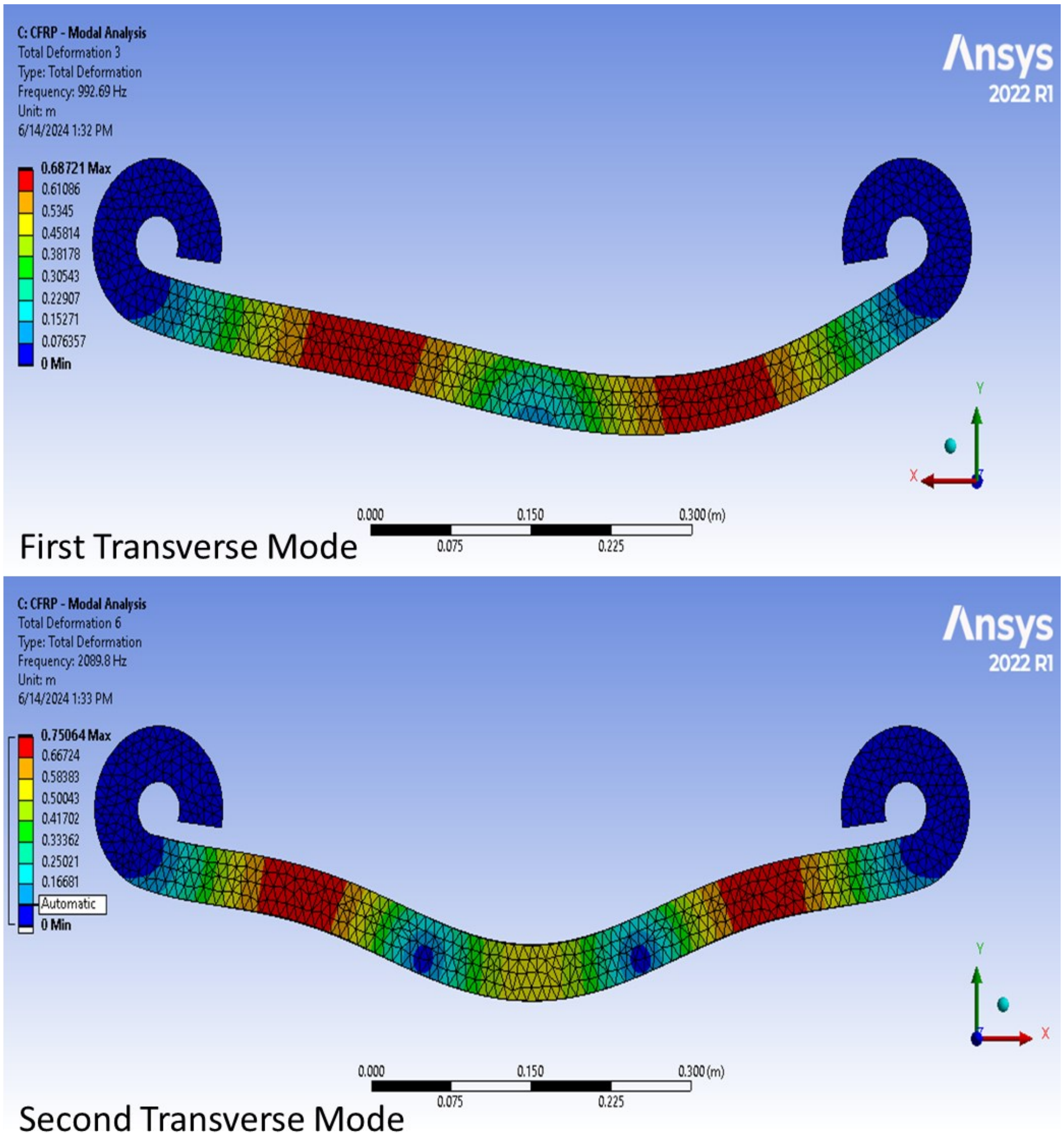


Figure 6.9: Transverse natural frequency for CFRP Leaf Spring

Figure 6.9 shows the modal analysis of CFRP leaf spring. As such, the natural frequency for the first mode of transverse vibration is 992.69 Hz. Whereas, the natural frequency for the second mode of transverse vibration is 2089.9 Hz. At the first mode of the transverse vibration, the maximum deformation is 0.68721 m. Whereas, At the second mode of the transverse vibration, the maximum deformation is 0.75064 m.

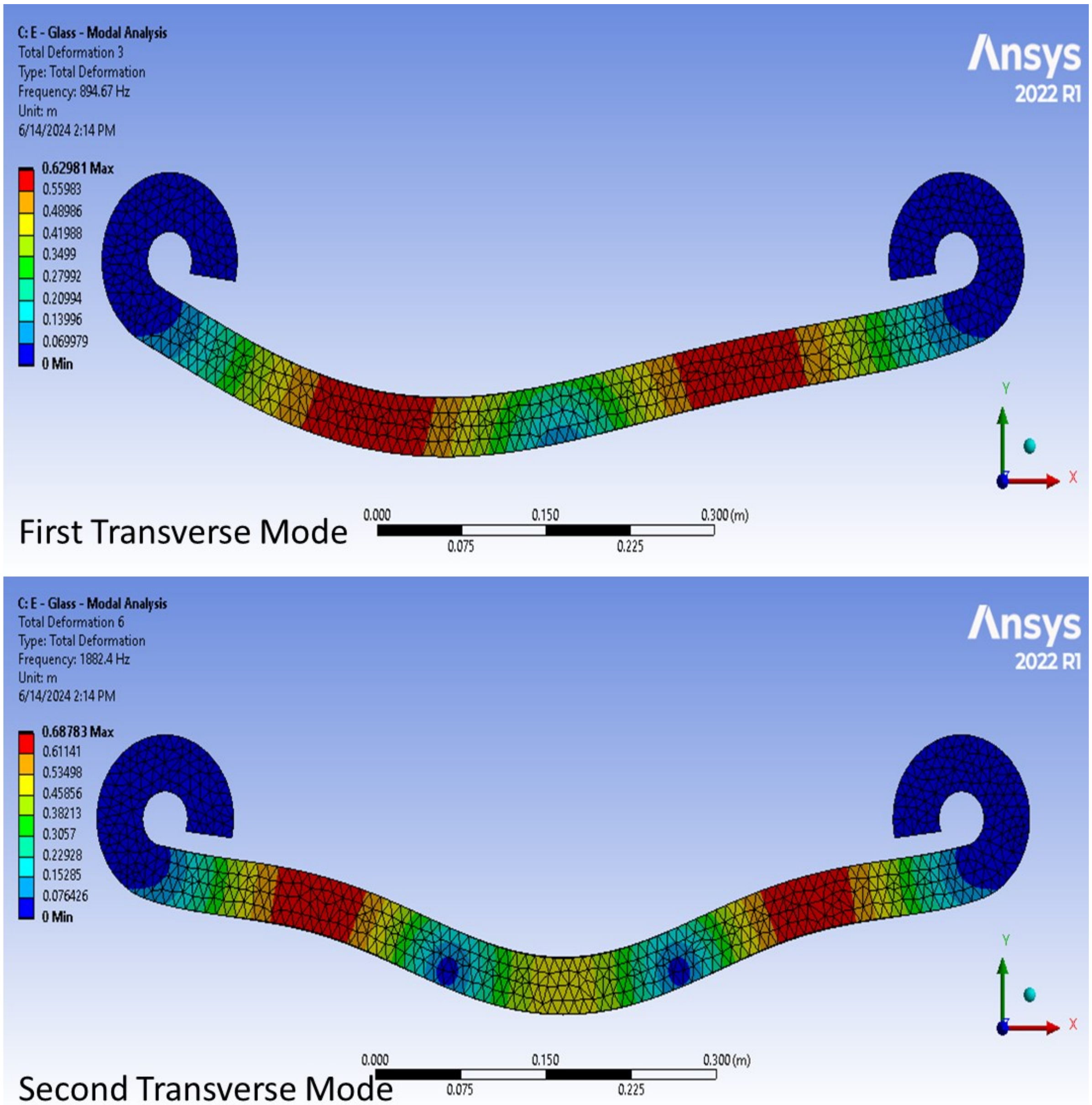


Figure 6.10: Transverse natural frequency for E – Glass Leaf Spring

Figure 6.10 shows the modal analysis of E – Glass leaf spring. As such, the natural frequency for the first mode of transverse vibration is 894.67 Hz. Whereas, the natural frequency for the second mode of transverse vibration is 1882.4 Hz. At the first mode of the transverse vibration, the maximum deformation is 0.62981 m. Whereas, At the second mode of the transverse vibration, the maximum deformation is 0.68783 m.

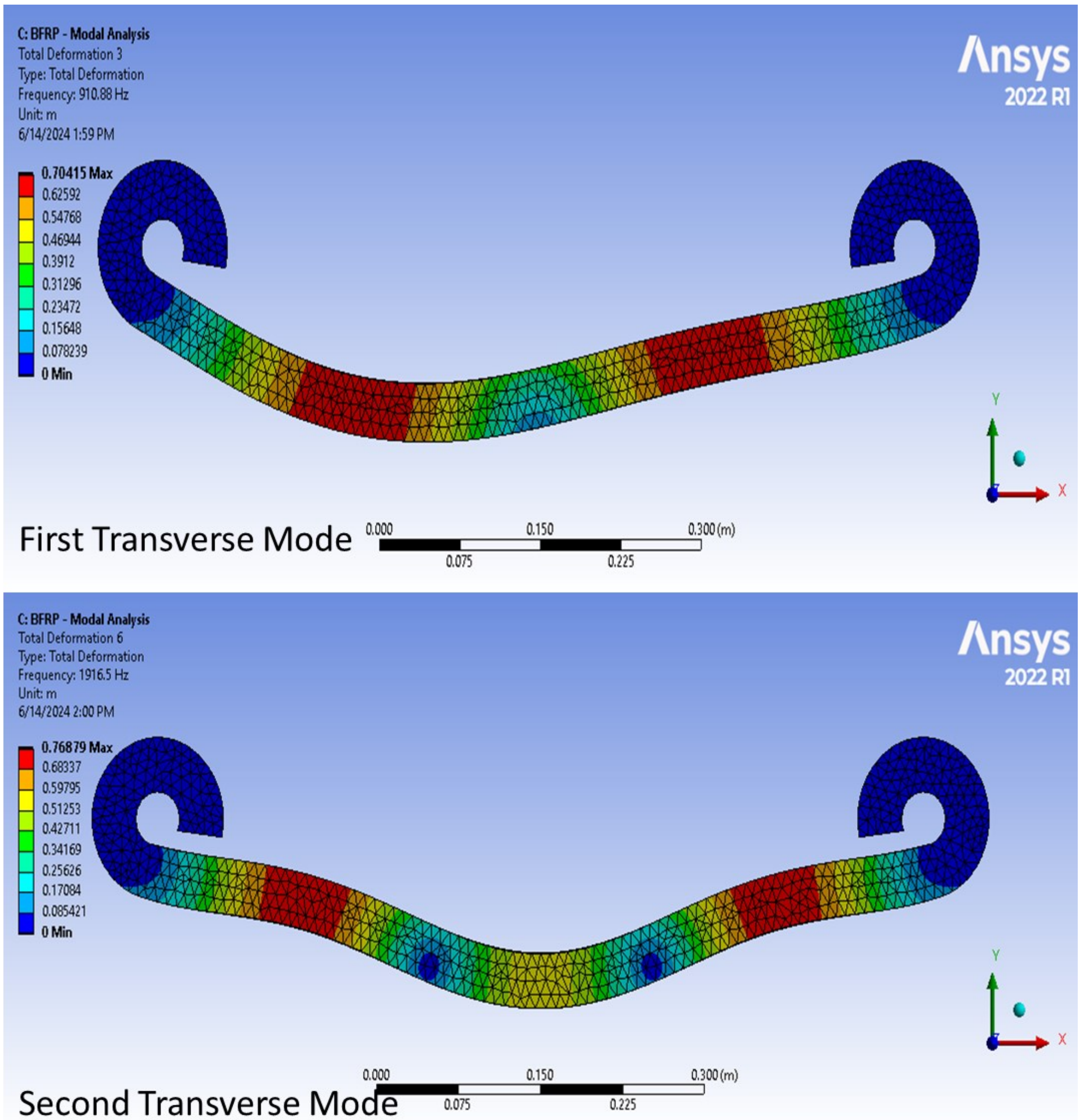


Figure 6.11: Transverse natural frequency for BFRP Leaf Spring

Figure 6.11 shows the modal analysis of BFRP leaf spring. As such, the natural frequency for the first mode of transverse vibration is 910.88 Hz. Whereas, the natural frequency for the second mode of transverse vibration is 1916.5 Hz. At the first mode of the transverse vibration, the maximum deformation is 0.70415 m. Whereas, At the second mode of the transverse vibration, the maximum deformation is 0.76879 m.

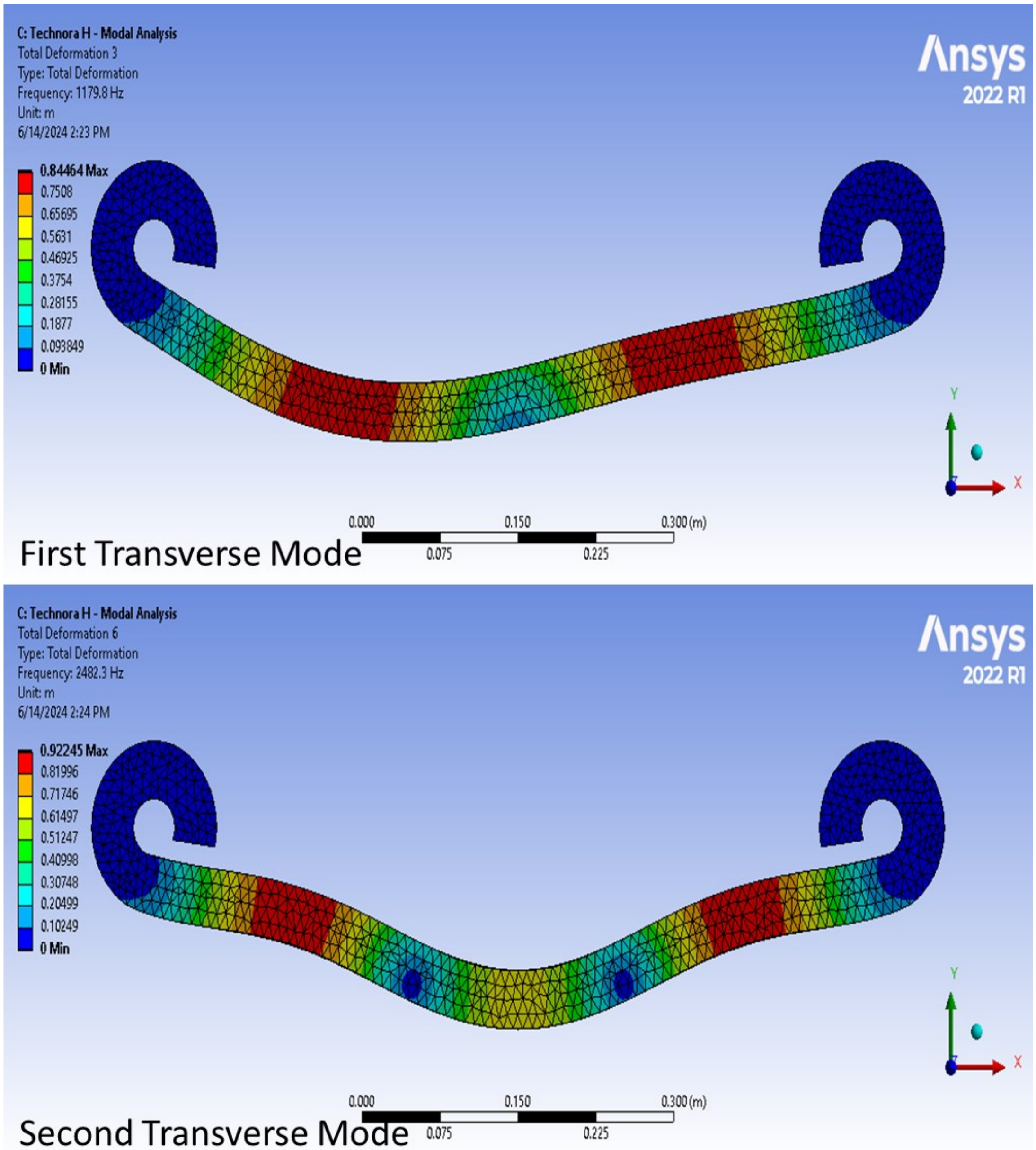


Figure 6.12: Transverse natural frequency for Technora H Leaf Spring

Figure 6.12 shows the modal analysis of Technora H leaf spring. As such, the natural frequency for the first mode of transverse vibration is 1179.8 Hz. Whereas, the natural frequency for the second mode of transverse vibration is 2482.3 Hz. At the first mode of the transverse vibration, the maximum deformation is 0.84464 m. Whereas, At the second mode of the transverse vibration, the maximum deformation is 0.92245 m.

Thus, as shown in *Table 6.3*, the results transverse vibration's natural frequencies for the composite materials are significantly higher compared to the conventional steel leaf spring for both first mode and the second mode. This indicates that the composite materials have higher stiffness and are less prone to vibration and resonance. Hence, the composite materials are more suitable for leaf springs due to their higher natural frequencies. These materials offer improved vibration isolation and reduced stress on the suspension system, which can lead to enhanced ride comfort and reduced fatigue life of the suspension components.

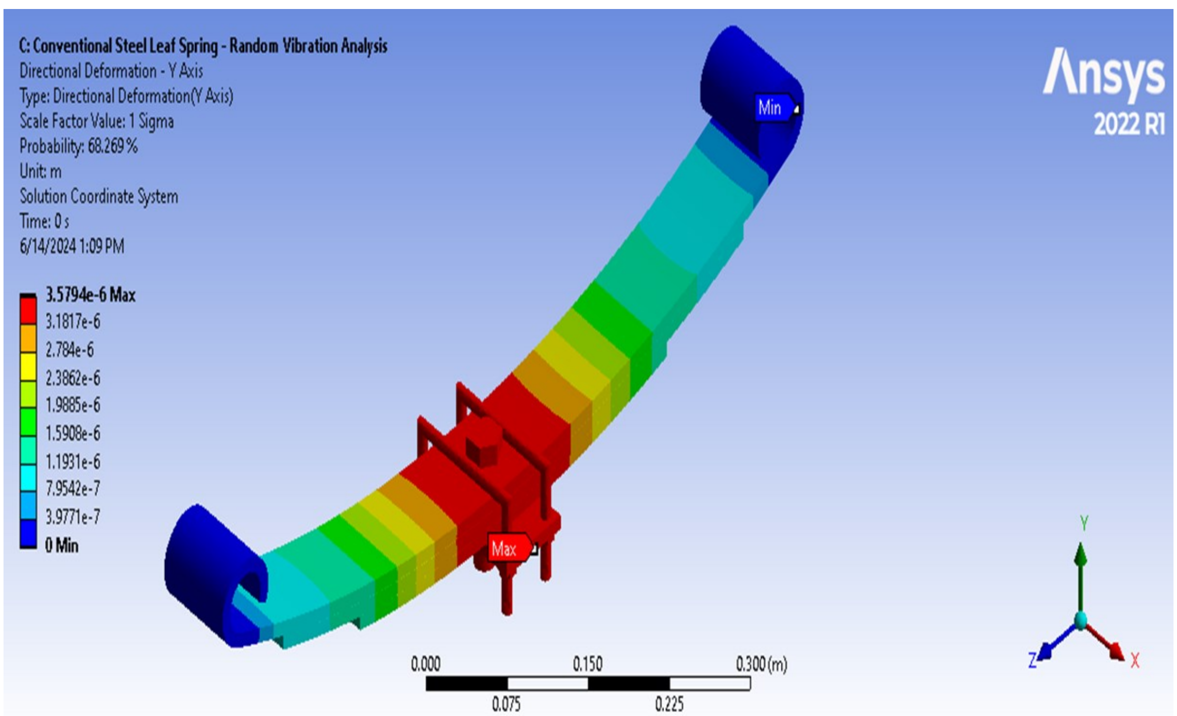


Figure 6.13: Amplitude of the transverse vibration for conventional Leaf Spring

Figure 6.13 shows the result of random vibration analysis for conventional steel leaf spring. As such, the amplitude of the transverse vibration for conventional steel leaf spring became 0.00358 mm.

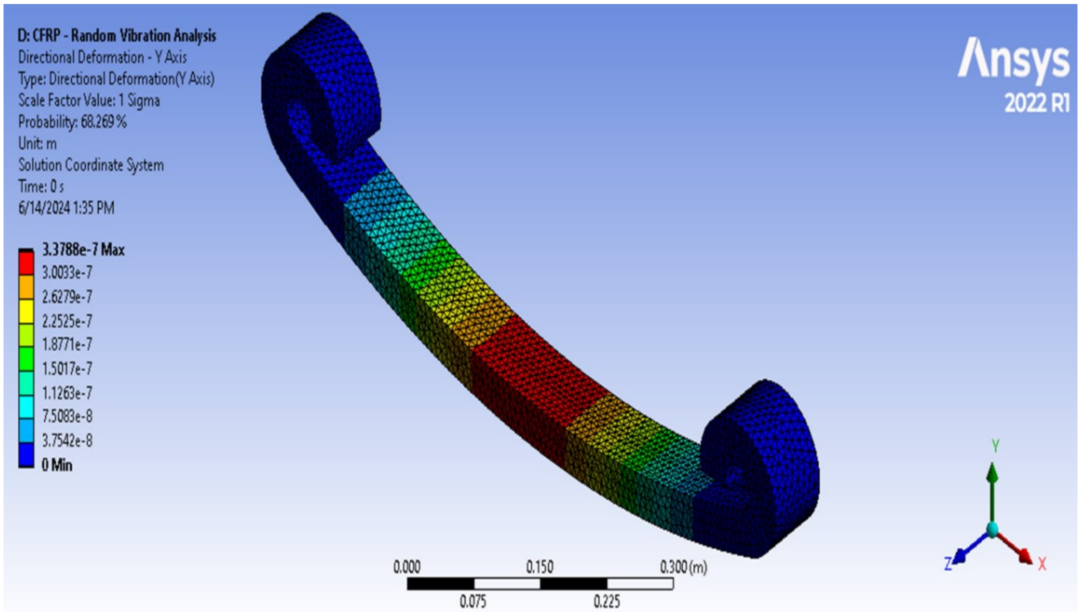


Figure 6.14: Amplitude of the transverse vibration for CFRP Leaf Spring

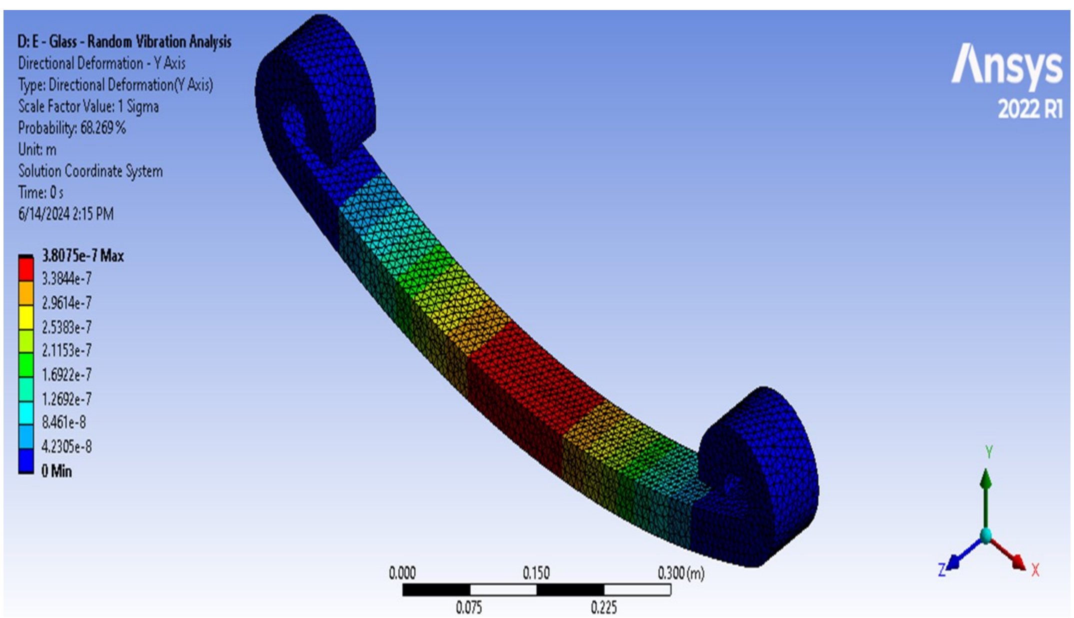


Figure 6.15: Amplitude of the transverse vibration for E – Glass Leaf Spring

Figure 6.14 shows the result of random vibration analysis for CFRP leaf spring. As such, the amplitude of the transverse vibration for CFRP leaf spring became 0.000338 mm. Whereas, *Figure 6.15* shows the result of random vibration analysis for E – Glass leaf spring. As such, the amplitude of the transverse vibration for E – Glass leaf spring became 0.00038 mm.

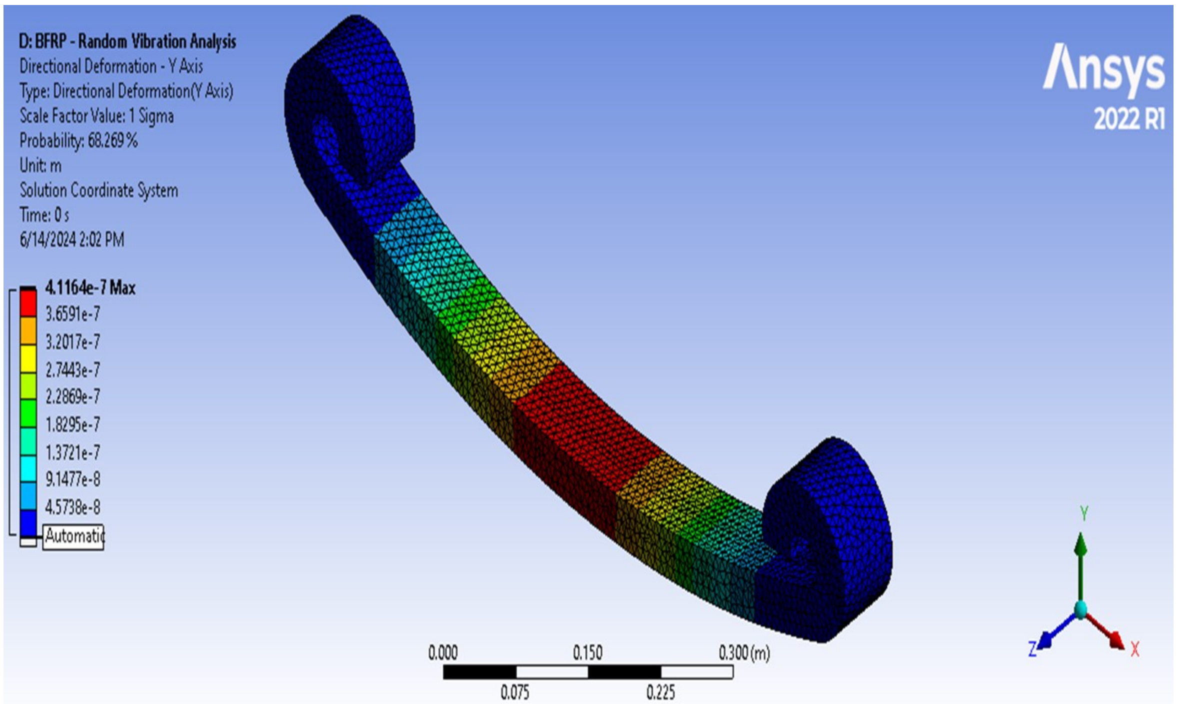


Figure 6.16: Amplitude of the transverse vibration for BFRP Leaf Spring

Moreover, *Figure 6.16* shows the result of random vibration analysis for BFRP leaf spring. As such, the amplitude of the transverse vibration for BFRP leaf spring became 0.000412 mm. Whereas, *Figure 6.17* shows the result of random vibration analysis for Technora H leaf spring. As such, the amplitude of the transverse vibration for Technora H leaf spring became 0.000294 mm.

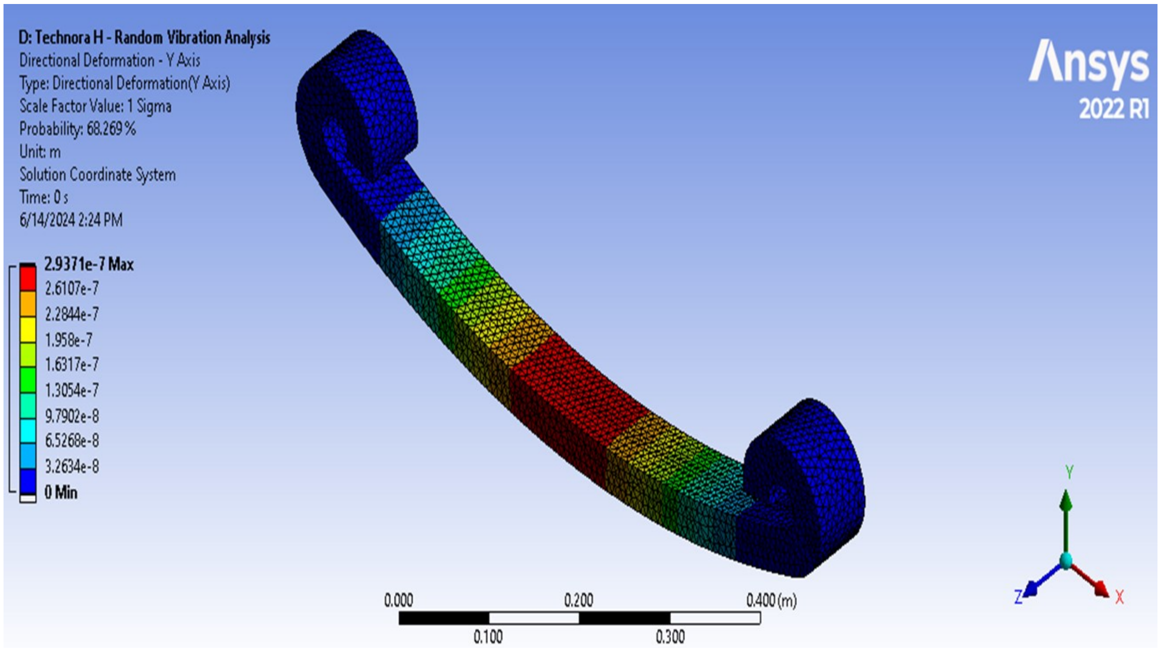


Figure 6.17: Amplitude of the transverse vibration for Technora H Leaf Spring

Furthermore, *Table 6.3* show that the amplitude of vibration for the conventional steel leaf spring is significantly higher compared to the composite materials. The composite material, particularly Technora H, exhibit much lower vibration amplitudes, indicating better vibration isolation and reduced stress on the suspension system. As such, the composite material, especially Technora H, are more suitable for leaf springs due to their lower vibration amplitudes.

Table 6.3: Vibration Analysis Results

S.No.	Material	Transverse Vibration Natural Frequency 1 (Hz)	Transverse Vibration Natural Frequency 1 (Hz)	Amplitude (mm)
1	Conventional Steel	417.38	990.89	3.58E-03
2	BFRP	910.88	1916.5	4.12E-04
3	E-Glass	894.77	1882.8	3.81E-04
4	CFRP	992.69	2089.8	3.38E-04
5	Technora H	1179.8	2482.3	2.94E-04

6.5. Fatigue Analysis

Fatigue analysis is performed to determine the number of life cycles before fatigue failure for various leaf spring models, using ANSYS static structural analysis. As such, number of life cycles to fatigue failure are obtained, as shown in *Figure 6.18* to *Figure 6.22*.

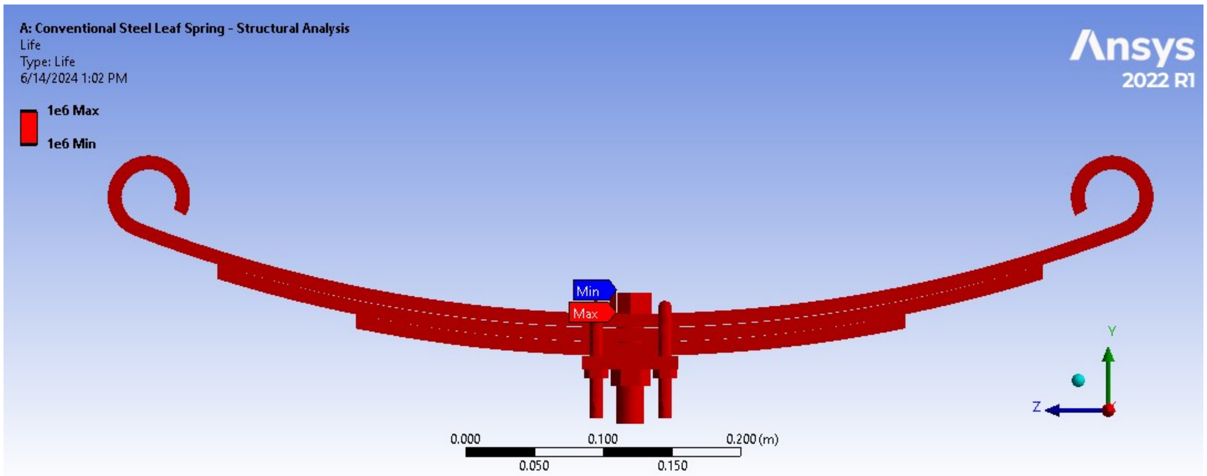


Figure 6.18: Number of life cycles to fatigue failure of conventional steel leaf spring

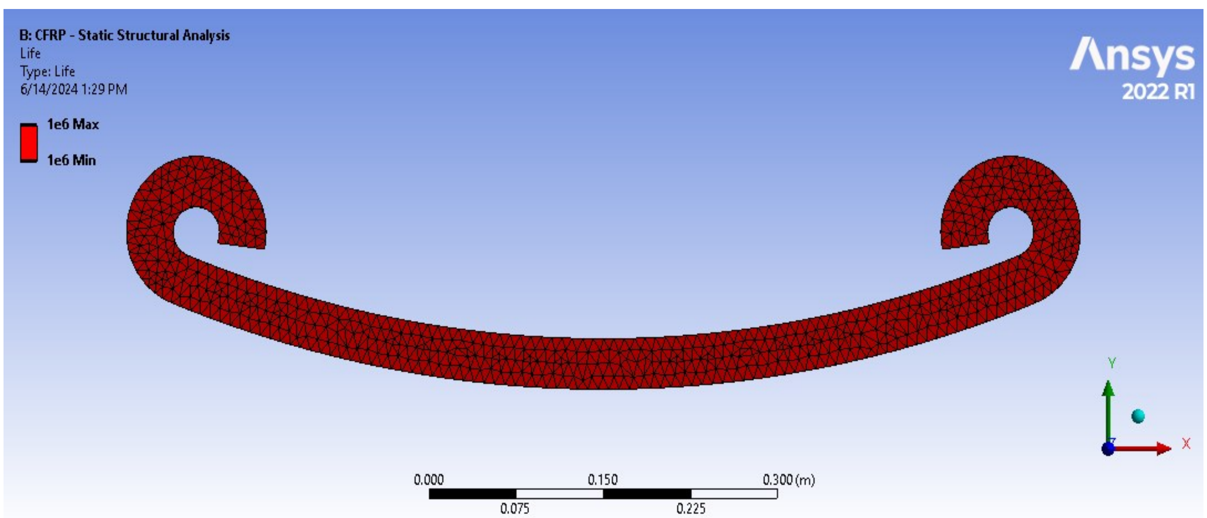


Figure 6.19: Number of life cycles to fatigue failure of CFRP leaf spring

Figure 6.18 shows the number of life cycles to fatigue failure of conventional steel leaf spring. As such, the number of life cycles for conventional steel leaf spring is one million cycles.

Similarly, *Figure 6.19* shows the number of life cycles to fatigue failure of CFRP leaf spring. As such, the number of life cycles for CFRP leaf spring is one million cycles.

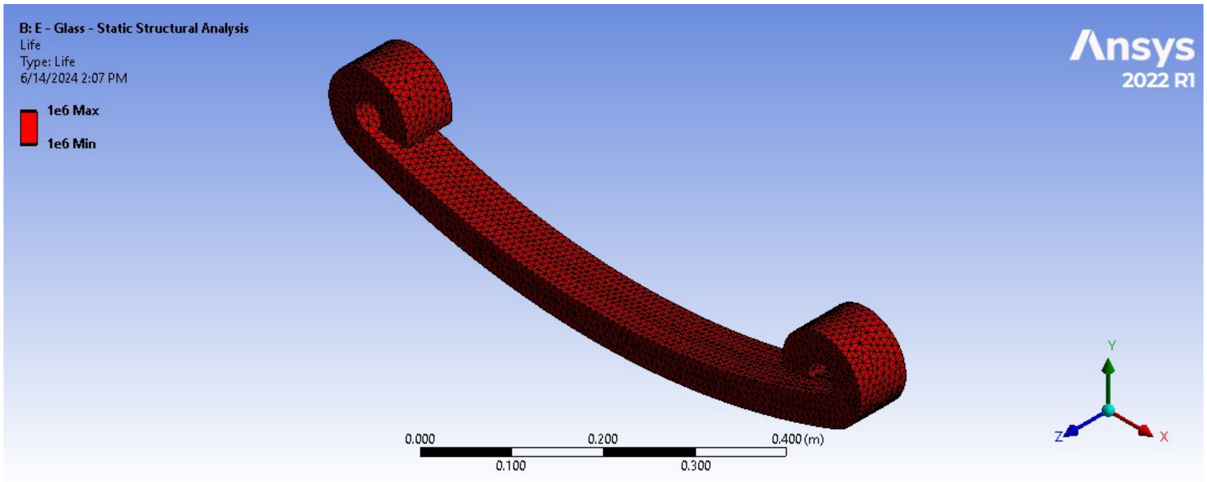


Figure 6.20: Number of life cycles to fatigue failure of E – Glass leaf spring

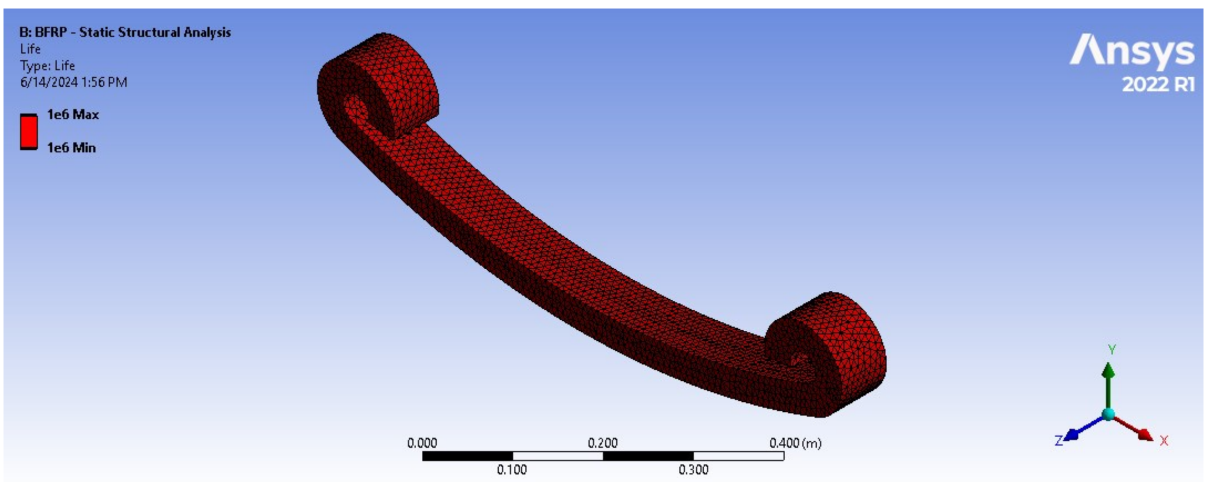


Figure 6.21: Number of life cycles to fatigue failure of BFRP leaf spring

In addition, *Figure 6.20* shows the number of life cycles to fatigue failure of E – Glass leaf spring. As such, the number of life cycles for E – Glass leaf spring is one million cycles. Similarly, *Figure 6.21* shows the number of life cycles to fatigue failure of BFRP leaf spring. As such, the number of life cycles for BFRP leaf spring is one million cycles. Moreover, *Figure 6.22* shows the number of life cycles to fatigue failure of Technora H leaf spring. As such, the number of life cycles for Technora H leaf spring is one million cycles. This indicates that, regarding the fatigue life, there is no significant difference between the conventional steel leaf spring and mono composite leaf springs.

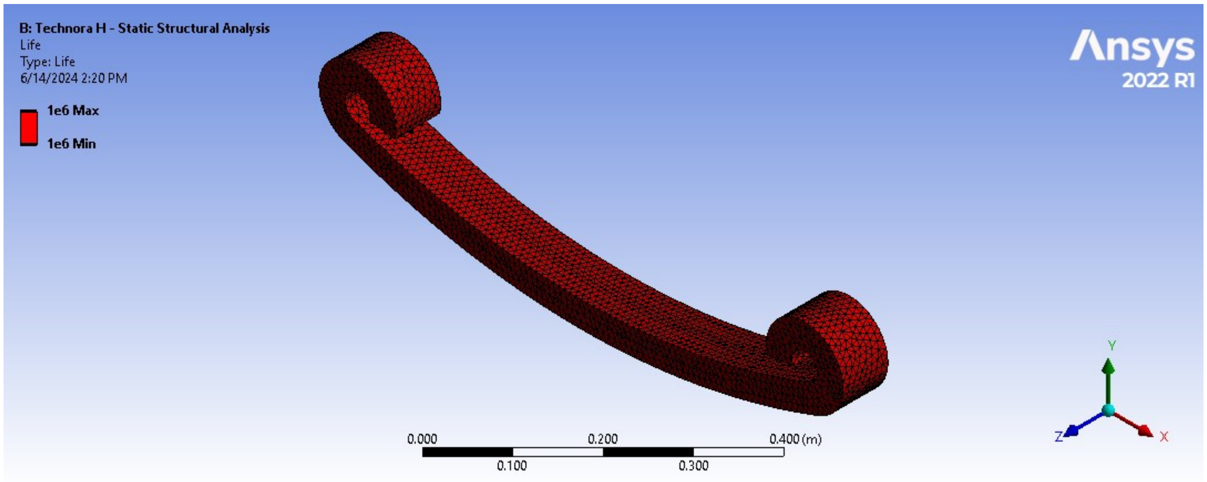


Figure 6.22: Number of cycles to fatigue failure of Technora H leaf spring

Furthermore, *Figure 6.23* shows the safety factor of a conventional steel leaf spring compared to CFRP, E-glass, Technora H, and BFRP leaf springs. The safety factor of a leaf spring is a measure of how much stronger the leaf spring is than the forces it is designed to withstand. A higher safety factor means that the leaf spring is less likely to fail. All of the alternative leaf springs have a higher safety factor than the conventional steel leaf spring. The highest safety factor is achieved by E – Glass, at 3.77.

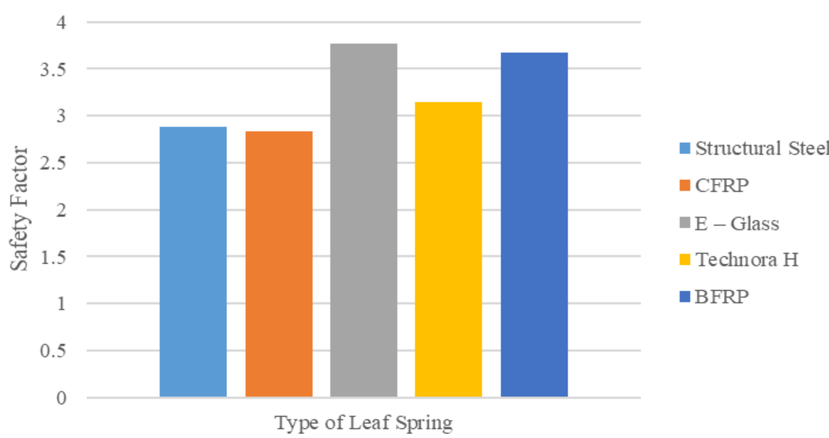


Figure 6.23: Comparison of safety factor of conventional steel leaf spring with MCLS

6.6. Summary of Results

Various modeling and analytical calculations are performed to analyze the potential of mono composite leaf spring to replace the conventional steel leaf spring. As such, Technora H leaf springs are the lightest with 5.44 kg, followed by BFRP, CFRP and E-glass leaf springs. Whereas, conventional steel leaf springs are the heaviest with 20.36 kg. Thus, the weight savings of Technora H leaf spring is up to 73%.

In addition, all of the alternative leaf springs provide better fuel economy than the conventional steel leaf spring with Technora H offering the best fuel economy at 8.68 km/liter. Whereas, BFRP and CFRP are also good choices with 8.59 and 8.58 km/liter respectively. Thus, the fuel saved per year by replacing conventional steel leaf spring with Technora H is the largest, at 44 liters per year estimated at 3451 Birr per year. BFRP and CFRP leaf springs also offer significant expense savings, with 1842 and 1638 Birr per year respectively.

Moreover, the total deformation of the conventional steel leaf spring is 0.05149 mm. Whereas, the total deformation of all the alternative leaf springs is higher than the conventional leaf spring, with BFRP having highest deformation of 0.08949 mm. Similarly, the maximum equivalent elastic strain of the conventional steel leaf spring is 0.30334 mm per meter of the length. Whereas, the maximum equivalent elastic strain of all the alternative leaf springs is higher than the conventional leaf spring, with BFRP having highest equivalent elastic strain 0.42253 mm per meter of the length. Furthermore, the maximum equivalent elastic stress of the conventional steel leaf spring, is 53.46 MPa. Whereas, the maximum equivalent elastic stress of all the alternative leaf springs is lower than the conventional leaf spring with 23.58 MPa.

Then, modal and vibration analysis are performed to determine the capabilities of various leaf spring models vibration isolation and reduced stress on the suspension system. As such, the natural frequency for the first and second mode of transverse vibration are 417.38 Hz. and 990.89 Hz, respectively. Whereas, the natural frequency for the first and second mode of transverse vibration for composite leaf springs are higher than the conventional leaf spring, with Technora H having highest first and second transverse natural frequency of 1179.8 Hz and 2482.3 Hz, respectively. This indicates that the composite materials have higher stiffness and are less prone to vibration and resonance. Hence, the composite materials are more suitable for leaf springs due to their higher natural frequencies.

Similarly, the amplitude of the transverse vibration for conventional steel leaf spring is 0.00358 mm. Whereas, the amplitude of the transverse vibration of composite leaf springs are lower than that of conventional steel leaf spring, with Technora H having lowest amplitude of the transverse vibration of 0.000294 mm. This indicates that, the composite material, particularly Technora H, exhibit much lower vibration amplitudes, indicating better vibration isolation and reduced stress on the suspension system. As such, the composite material, especially Technora H, are more suitable for leaf springs due to their lower vibration amplitudes.

Then, fatigue analysis is performed to determine the number of life cycles before fatigue failure for various leaf spring models, using ANSYS static structural analysis. As such, number of life cycles to fatigue failure are obtained. However, both the conventional steel leaf spring and mono composite leaf spring have one million number of life cycles. This indicates that, regarding the fatigue life, there is no significant difference between the conventional steel leaf spring and mono composite leaf springs. Furthermore, the safety factor of a conventional steel leaf spring is compared to MCLS. As such, all of the alternative leaf springs have a higher safety factor than the conventional steel leaf spring with E – Glass having highest safety factor of 3.77.

Table 6.4 summarizes the rank of the leaf springs considering parameters such as weight, fuel economy, deformation, strain, stress, safety factor, natural frequency, and vibration amplitude. Maximum value of 5 is assigned for the required parameter. For instance, low weight, high fuel economy, low deformation, low strain, low stress, high safety factor, high natural frequency, and low vibration amplitudes are required. As such, Technora H ranks first with the score of 32. Moreover, all of the alternate leaf spring outscored the conventional steel leaf spring.

Table 6.4: Summary of the various parameters of leaf springs

S.No.	Type of leaf spring	Value									Rank
		Weight	Fuel	Deformation	Strain	Stress	Safety factor	Natural Frequency (2)	Amplitude	Total	
1	Conventional steel	1	1	5	5	1	2	1	1	17	5
2	CFRP	3	3	4	4	5	1	4	4	28	2
3	E – Glass	2	2	3	3	5	5	2	2	24	4
4	Technora H	5	5	2	2	5	3	5	5	32	1
5	BFRP	4	4	1	1	5	4	3	3	25	3

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATION

7.1. Conclusion

The conventional steel leaf springs are very heavy and account for 10-20% of the unsprung weight of the vehicle. However, there is a possibility of reducing weight in order to improve fuel economy. Hence, in this thesis, various modeling and analytical calculations are performed to analyze the potential of mono composite leaf spring to replace the conventional steel leaf spring. The model is designed based on the design specifications acquired from Toyota Tacoma SR 2020 model. As such, Technora H leaf spring is the lightest with 5.44 kg. Whereas, conventional steel leaf spring is the heaviest with 20.36 kg. Thus, Technora H leaf spring can save 73% of leaf spring weight. In addition, all of the alternative leaf springs provide better fuel economy than the conventional steel leaf spring with Technora H offering the best fuel economy at 8.68 km/liter. Thus, the fuel saved per year by replacing conventional steel leaf spring with Technora H is the largest, at 44 liters per year estimated at 3451 Birr per year.

However, the total deformation of all the alternative leaf springs is higher than the conventional leaf spring, with BFRP having highest deformation of 0.08949 mm. Similarly, the maximum equivalent elastic strain of all the alternative leaf springs is higher than the conventional leaf spring, with BFRP having highest equivalent elastic strain 0.42253 mm per meter of the length. Furthermore*,* the maximum equivalent elastic stress of all the alternative leaf springs is lower than the conventional leaf spring with 23.58 MPa.

In addition, the natural frequency for the first and second mode of transverse vibration for composite leaf springs are higher than the conventional leaf spring, with Technora H having highest first and second transverse natural frequency of 1179.8 Hz and 2482.3 Hz, respectively. Similarly, the amplitude of the transverse vibration of composite leaf springs are lower than that of conventional steel leaf spring, with Technora H having lowest amplitude of the transverse vibration of 0.000294 mm. This indicates that, the composite material, particularly Technora H, exhibit much lower vibration amplitudes, indicating better vibration isolation.

Moreover, all of the alternative leaf springs have a higher safety factor than the conventional steel leaf spring with E – Glass having highest safety factor of 3.77.

Furthermore, by considering low weight, high fuel economy (low fuel consumption), low deformation, low strain, low stress, high safety factor, high natural frequency, and low vibration amplitudes, Technora H ranks first with the score of 22. Moreover, all of the alternate leaf spring outscored the conventional steel leaf spring.

Hence, it can be concluded that,

- MCLS are lighter than conventional steel leaf springs,
- MCLS have better fuel economy (low fuel consumption) than conventional steel leaf springs,
- MCLS have high safety factor than conventional steel leaf springs,
- MCLS have high transverse natural frequency than conventional steel leaf springs, and
- MCLS have low transverse vibration amplitude than conventional steel leaf springs.

Thus, MCLS can replace conventional steel leaf spring for the benefit of weight reduction and better fuel economy.

7.2. Recommendation

Modeling and FEA of a mono composite leaf spring for lightweight vehicles to reduce the vehicle weight and improve its fuel economy. However, the component is only analyzed in terms of static force. However, there may be other factors that may be need to considered. And, in addition ANSYS static structural is used to for FEA. Thus, it is recommended that:

- Other load factors such as vibration, fatigue analysis and modal analysis could be considered for further analysis.

.

REFERENCES

Abbood, I. S., Odaa, S. aldeen, Hasan, K. F., and Jasim, M. A. (2021). Properties evaluation of fiber reinforced polymers and their constituent materials used in structures – A review. *Materials Today: Proceedings*, *43*, 1003–1008. https://doi.org/10.1016/j.matpr.2020.07.636

Aggarwal, S., Aggarwal, M. L., and Verma, K. (2022). Investigation regarding the Replacement of Composite Material Leaf Springs with Spring Steel Leaf Springs in Automotive Vehicles : A Review. *International Conference on Material Science and Engineering*. https://doi.org/10.1088/1757-899X/1248/1/012080

ANSYS. (2021). *Products*. https://www.ansys.com/products#t=ProductsTab&sort=relevancy&layout=card&numberOfResults=21

Ashwini, K., and Rao, C. V. M. (2018). Design and Analysis of Leaf Spring using Various Composites – An Overview. *Materials Today: Proceedings*, *5*(2), 5716–5721. https://doi.org/10.1016/j.matpr.2017.12.166

Assarudeen, H., and Anandkumar, G. (2015). Structural Analysis of Banana/E-Glass Woven Fiber Reinforced Epoxy Based Hybrid Composite on Mono Leaf Spring Using FEA. *National Conference On Recent Trends And Developments In Sustainable Green Technologies*, *7*, 253–257.

Batu, T., Lemu, H. G., and Michael, E. G. (2021). Multi objective parametric optimization and composite material performance study for master leaf spring. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2021.01.925

Bhandari, B. A., and Patel, B. C. (2014). Parametric Analysis Of Composite Leaf Spring. *International Journal of Science Technology & Engineering*, *1*(1), 22–27.

Bidve, M. A., and Billore, M. (2022). Design Optimization and Analysis of Composite Leaf Spring for Light Weight Vehicle. *International Journal of Mechanical and Production Engineering Research and Development*, *12*(1), 107–112.

Blanco, S. (2016). *How does weight affect a vehicle's efficiency?* Autoblog. https://www.autoblog.com/2009/10/29/greenlings-how-does-weight-affect-a-vehicles-efficiency/

Capitol Technology University. (2019). *What is SOLIDWORKS?* https://www.captechu.edu/blog/solidworks-mechatronics-design-and-engineering-program

Chavhan, G. R., and Chilbule, P. V. (2018). Design and Analysis of Leaf Spring using Composite Materials. *International Journal of Engineering Research & Technology*, *7*(05), 569–576.

Chavhan, G. R., and Wankhade, L. N. (2019). Experimental analysis of E-glass fiber / epoxy composite-material leaf spring used in automotive. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2019.12.058

Cheah, L. W., and Heywood, J. B. (2010). *Cars on a Diet : The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the U . S .*

Degu, B. B. (2022). *Design And Analysis of Mono Composite Leaf Spring for Light Weight Vehicles*. *11*(08), 263–269.

Faris, W. F., Rakha, H. A., Kafafy, R. I., Idres, M., and Elmoselhy, S. (2011). Vehicle fuel consumption and emission modelling : an in-depth literature review. *Int. J. Vehicle Systems Modelling and Testing*, *6*(3), 318–395.

Fernie, M. (2016). *The Advantages And Disadvantages Of Leaf Springs*. Car Throttle. https://www.carthrottle.com/news/advantages-and-disadvantages-leaf-springs

Greene, D. L. (2010). *How Consumers Value Fuel Economy : A Literature Review*.

Huang, S., and Dao, T.-P. (2016). Design and Computational Optimization of a Flexure- based XY Positioning Platform using FEA-based Response Surface Methodology. *International Journal of Precision Engineering and Manufacturing*, *17*(8), 1035–1048. https://doi.org/10.1007/s12541-016-0126-5

Jadhao, K. K., and Dalu, R. S. (2014). *Design and Analysis of Composite Leaf Spring : A Review*. *5762*, 67–72.

Jaiswal, S. K., Gajbhiye, S. C., Kumar, S., and Sidar, P. (2022). Comparative FE Analysis of Automotive Leaf Spring Using Composite Materials. *International Journal of Mechanical and Production Engineering Research and Development*, *12*(1), 31–52.

Kalwaghe, R. N., and Sontakke, K. R. (2014). Design And Analysis Of Composite Leaf Spring By Using FEA And Ansys. *International Journal Of Scientific Engineering And Research*, *3*(5).

Kapadia, D., Desai, P. H., and Sonani, A. (2016). Design and Analysis of Composite Leaf Spring for Light Weight vehicle. *International Journal of Engineering Sciences & Research Technology*, *5*(6), 666–672.

Katu, A. R., Gund, S. P., and Raut, L. B. (2015). Review of Design and Analysis of Composite Material Mono Leaf Spring. *International Journal of Innovation in Engineering, Research and Tecnology*.

Ke, J., Wu, Z., Chen, X., and Ying, Z. (2019). A review on material selection , design method and performance investigation of composite leaf springs. *Composite Structures*, *226*, 111277. https://doi.org/10.1016/j.compstruct.2019.111277

Kessentini, A., Mohammed, G., Ahmed, S., and Madiouli, J. (2019). Design Optimization and FE Analysis of 3D Printed Carbon PEEK Based Mono Leaf Spring. *Micromachines*, *10*.

Khurmi, R. S., and Gupta, J. K. (2005). *A textbook of Machine Design* (First Mult). Eurasia Publishing House (Pvt.) Ltd.

Kong, Y. S., Abdullah, S., Omar, M. Z., and Haris, S. M. (2016). Failure assessment of a leaf spring eye design under various load cases. *Engineering Failure Analysis*, *63*, 146–159. https://doi.org/10.1016/j.engfailanal.2016.02.017

Krishna, R., Guduru, R., Hussain, S., Patel, H., and Domeika, A. (2020). Development of mono leaf spring with composite material and investigating its mechanical properties. *Materials*

Today: Proceedings, 2–7. https://doi.org/10.1016/j.matpr.2020.02.289

Krishnamurthy, K., Ravichandran, P., Naufal, A. S., Pradeep, R., and Harishadithiya, K. M. S. (2020). Modeling and structural analysis of leaf spring using composite materials. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.07.346

Kulkarni, K. S., and Khot, V. J. (2015). Design and Development of Mono Leaf Spring by using Composite Material (Epoxy-Carbon Fiber). *International Journal of Advanced Engineering Research and Science*, *2*(12).

Kumar, A., Shinde, V. J., and Chavan, S. S. (2014). Design, Analysis, Manufacturing and Testing of Mono Composite Leaf Spring Using UD E-Glass Fiber/Epoxy. *International Journal of Advanced Technology in Engineering and Science*, *02*(12), 112–121.

Kumar, H. V., Sivakumar, A., Gowshik, G., Deepanraj, S., and Prabakaran, R. (2021). Analyze the Design of Leaf spring by Solid works and Ansys to Improve the Vehicle Performance. *Annals of R.S.C.B.*, *25*(5), 1864–1875.

Li, B., Zhang, Q., Yang, J., Li, W., Wu, H., and Zheng, X. (2022). Research on the Application of New Composite Leaf Springs for Commercial Vehicles. *Innovation in Science and Technology*, *1*(2), 42–45. https://doi.org/10.56397/IST.2022.09.05

Lipshaw, J. (2020). *What is Lightweighting and How Does it Improve Fuel Economy in Vehicles?* Union of Concerned Scientists - The Equation. https://blog.ucsusa.org/science-blogger/lightweighting-and-fuel-economy-in-vehicles/

Ma, L., He, J., Gu, Y., Zhang, Z., Yu, Z., Zhou, A., and Tam, L. (2021). Structure Design of GFRP Composite Leaf Spring : An Experimental and Finite Element Analysis. *Polymers*, *13*, 1–22.

Mahanthi, D. L., and Murali, C. V. S. (2017). Design and analysis of composite Leaf Spring for light Weight Vehicle. *International Journal of Advanced Engineering Research and Science*, *4*(3).

Manaba, B., and Hashe, V. T. (2021). A review of composite leaf springs for automotive vehicles. *MATEC Web of Conferences*, *347*, 1–8.

Manchanda, S., Singh, B., and Singh, G. (2015). Design and Finite Element Analysis of Leaf Spring Using Different Material Properties. *Journal of Academia and Industrial Research*, *4*(7), 186–189.

Mehndiratta, A., Singh, N. K., and Singh, K. K. (2015). Analysis of GFRP Leaf Spring. *International Journal of Modern Engineering Research*, *5*, 22–27.

Mosleh, A., Alher, M. A., Ballabio, A., Iacovo, A. De, Cell, O., Redox, D., Abaza, A., Meille, S., and Nakajo, A. (2022). Weight optimization and finite element analysis of automobile leaf spring : A design construction referred to electric vehicle. *IOP Conference Series: Materials Science and Engineering PAPER*. https://doi.org/10.1088/1757-899X/1259/1/012024

Mundale, S., Pawar, P. D. B., Verma, P. D. J., E. Y., Cad, M. E., and P. V. B. (2017). Design and Analysis of Composite Leaf Spring Using Composite Material for Light Vehicle - A Review. *International Journal of Interdisciplinary Innovative Research &Development*, *01*(02), 122–126.

Nutalapati, S. (2015). Design and Analysis of Leaf Spring by Using Composite Material for Light Vehicles. *International Journal of Mechanical Engineering and Technology*, *6*(12), 36–59.

Office of Energy Efficiency and Renewable Energy. (2022). *Lightweight and Propulsion Materials*. https://www.energy.gov/eere/vehicles/lightweight-and-propulsion-materials

Paramitha, N., Utami, E., Mahendra, N. Y., Prakoso, A. T., and Akbar, I. (2022). Material Selection and Mechanical Properties in Leaf Spring Application: A Review. *Austenit*, *14*(2), 2022. http://doi.org/10.5281/zenodo.72 97749

Patel, J. R. (2014). *Design and analysis of composite leaf spring*. Ganpat University.

Qian, C., Shi, W., Chen, Z., Yang, S., and Song, Q. (2017). Fatigue Reliability Design of Composite Leaf Springs Based on Ply Scheme Optimization. *Composite Structures*.

https://doi.org/10.1016/j.compstruct.2017.02.035

Rai, V., and Saxena, G. (2013). Development of a Composite Leaf Spring for a Light Commercial Vehicle (Tata Magic). *Int. Journal of Engineering Research and Applications*, *3*(5), 110–114.

Rajak, D. K., Pagar, D. D., Menezes, P. L., and Linul, E. (2019). Fiber-Reinforced Polymer Composites: Manufacturing, Properties, and Applications Dipen. *Polymers*, *11*.

Rajamanickam, R. K., Durvasulu, R., and Moorthi, S. (2022). Investigation on Mechanical Properties of Carbon Fiber Composite Using FEM for Leaf Spring Applications. *Journal Aerospace Technology Management*, *14*.

Ravindra, P., Raman, M., and Sanjay, B. (2014). Modeling and Analysis of Carbon Fiber Epoxy Based Leaf Spring under the Static Load Condition by Using FEA. *International Journal of Emerging Science and Engineering*, *2*(4), 39–42.

Robinson, A. L., Taub, A. I., and Keoleian, G. A. (2019). *Fuel efficiency drives the auto industry to reduce vehicle weight*. MRS Bulletin. https://doi.org/https://doi.org/10.1557/mrs.2019.298

Saini, P., Goel, A., and Kumar, D. (2013). Design and Analysis of Composite Leaf Spring for Light Vehicles. *International Journal of Innovative Research in Science, Engineering and Technology*, *2*(5), 1–10.

Sajan, S., and Selvaraj, D. P. (2021). A review on polymer matrix composite materials and their applications. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2021.08.034

Salman, M. K., Singh, A. P., Roy, S., and Banerjee, J. (2018). Numerical Investigation Of Parabolic Leaf Spring For Composite Materials Using Ansys. *Int. Journal of Engineering Research and Application ISSN:*, *8*(1), 58–69. https://doi.org/10.9790/9622-0801015869

Seeger Toyota. (2020). *Toyota Tacoma Trim Level and Price Differences*. https://www.seegertoyota.com/research-tacoma-trims.html

Shukoor, S. A., and Rao, N. A. N. (2017). Fabrication, Design Optimization, And Stress Analysis Of Mono Leaf Spring Using Metal-Matrix Composites. *International Journal of Innovative Technology and Research*, *5*(3), 6073–6077.

Singh, V., and Rastogi, V. (2021). Design and Static Analysis of Mono Composite Leaf Spring Made of Various Types of Composite Materials Using Finite Element Method. *IOP Conference Series: Materials Science and Engineering*. https://doi.org/10.1088/1757-899X/1033/1/012041

Solidworks. (2022). *Why Choose SOLIDWORKS 3D CAD?* https://www.solidworks.com/product/solidworks-3d-cad

Tadesse, B. A., and Fatoba, O. (2022). Design optimization and numerical analyses of composite leaf spring in a heavy-duty truck vehicle. *Materials Today: Proceedings*, *62*, 2814–2821. https://doi.org/10.1016/j.matpr.2022.02.367

Toyota. (2020). *Toyota Tacoma*. https://www.toyota.com/tacoma/2020/features/mpg_other_price/7594/7544/7582/

U.S. Department of Energy. (2022). *Lightweight Materials for Cars and Trucks*. https://www.energy.gov/eere/vehicles/lightweight-materials-cars-and-trucks

Umanath, K., Prabhu, M. K., Yuvaraj, A., and Devika, D. (2020). Fabrication and analysis of Master leaf spring plate using carbon fibre and pineapple leaf fibre as natural composite materials. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.03.790

Utami, N. P. E., Mahendra, N. Y., Prakoso, A. T., Akbar, I., Gunawan, Putra, D. P., Romli, Fatoni, Z., and Pratiwi, D. K. (2022). Material Selection and Mechanical Properties in Leaf Spring Application : A Review. *Austenit*, *14*(2).

Varma, N., Ahuja, R., Vijayakumar, T., and Kannan, C. (2020). Design and analysis of composite mono leaf spring for passenger cars. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2020.10.073

Venkatesan, M., and Devaraj, D. H. (2012). Design and Analysis of Composite Leaf Spring in

Light Vehicle. *International Journal of Modern Engineering Research*, *2*(1), 213–218.

Wang, T., Tinsley, B., Patel, M. D., and Shabana, A. A. (2018). Nonlinear dynamic analysis of parabolic leaf springs using ANCF geometry and data acquisition. *Nonlinear Dynamics*. https://doi.org/10.1007/s11071-018-4338-3

Yang, S., Shi, W., Chen, Z., Qian, C., and Yang, C. (2019). Composite mechanics and energy method based stiffness prediction model for composite leaf springs. *Mechanics Based Design of Structures and Machines*, 1–12. https://doi.org/10.1080/15397734.2018.1559738

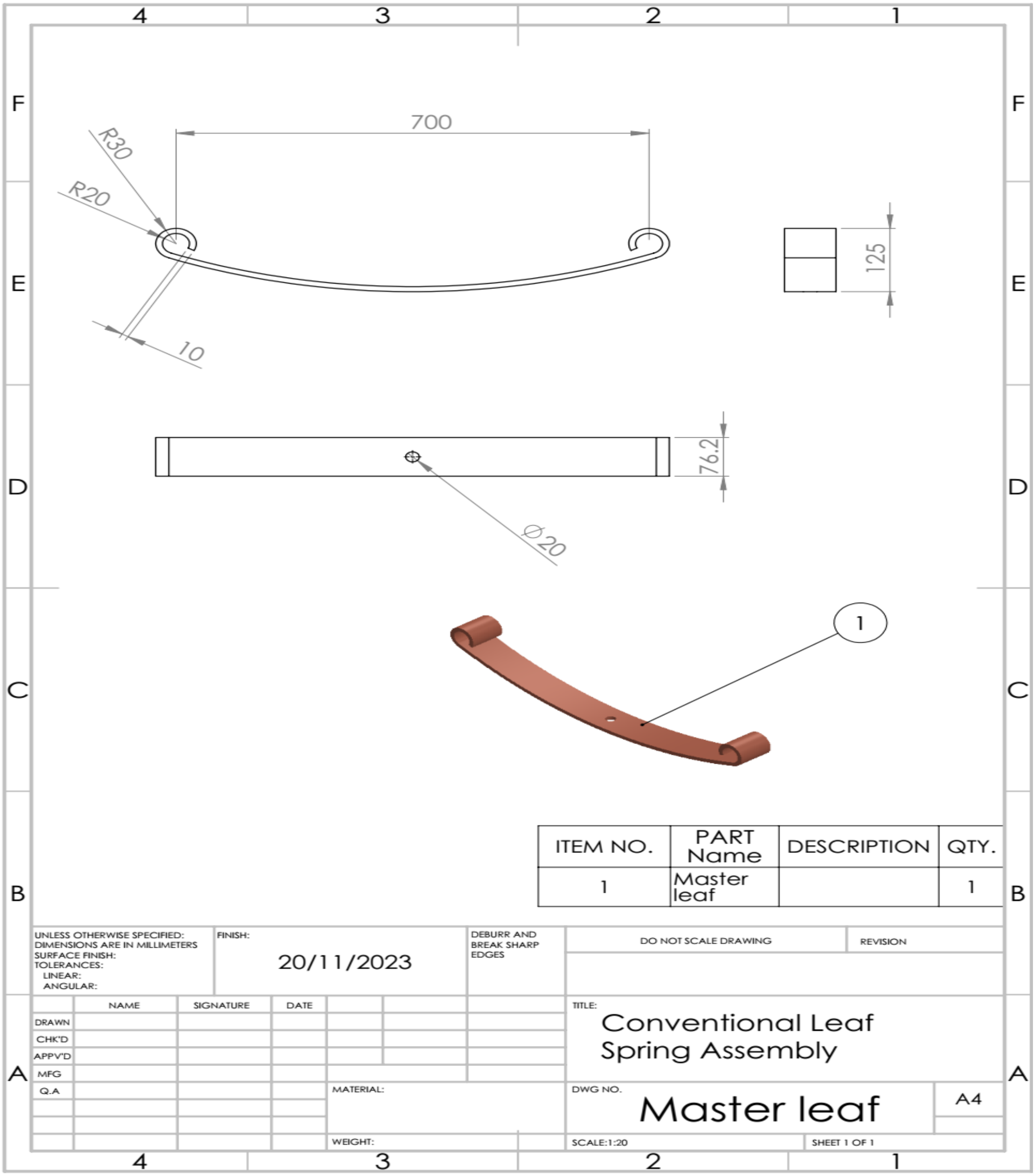
Zardi, M. A. A., and Kolur, P. C. (2019). FEA Analysis of Composite Leaf Spring Using Ansys. *International Journal of Innovative Research in Science, Engineering and Technology*, *8*(2), 1356–1363. https://doi.org/10.15680/IJIRSET.2019.0802077

Zhou, M., Jin, H., and Wang, W. (2016). A review of vehicle fuel consumption models to evaluate eco-driving and eco-routing. *Transportation Research Part D*, *49*(5), 203–218. https://doi.org/10.1016/j.trd.2016.09.008

Zou, X., Zhang, B., and Yin, G. (2022). Analysis of stiffness and damping performance of the composite leaf spring. *Scientific Reports*, *12*, 1–10. https://doi.org/10.1038/s41598-022-11055-5

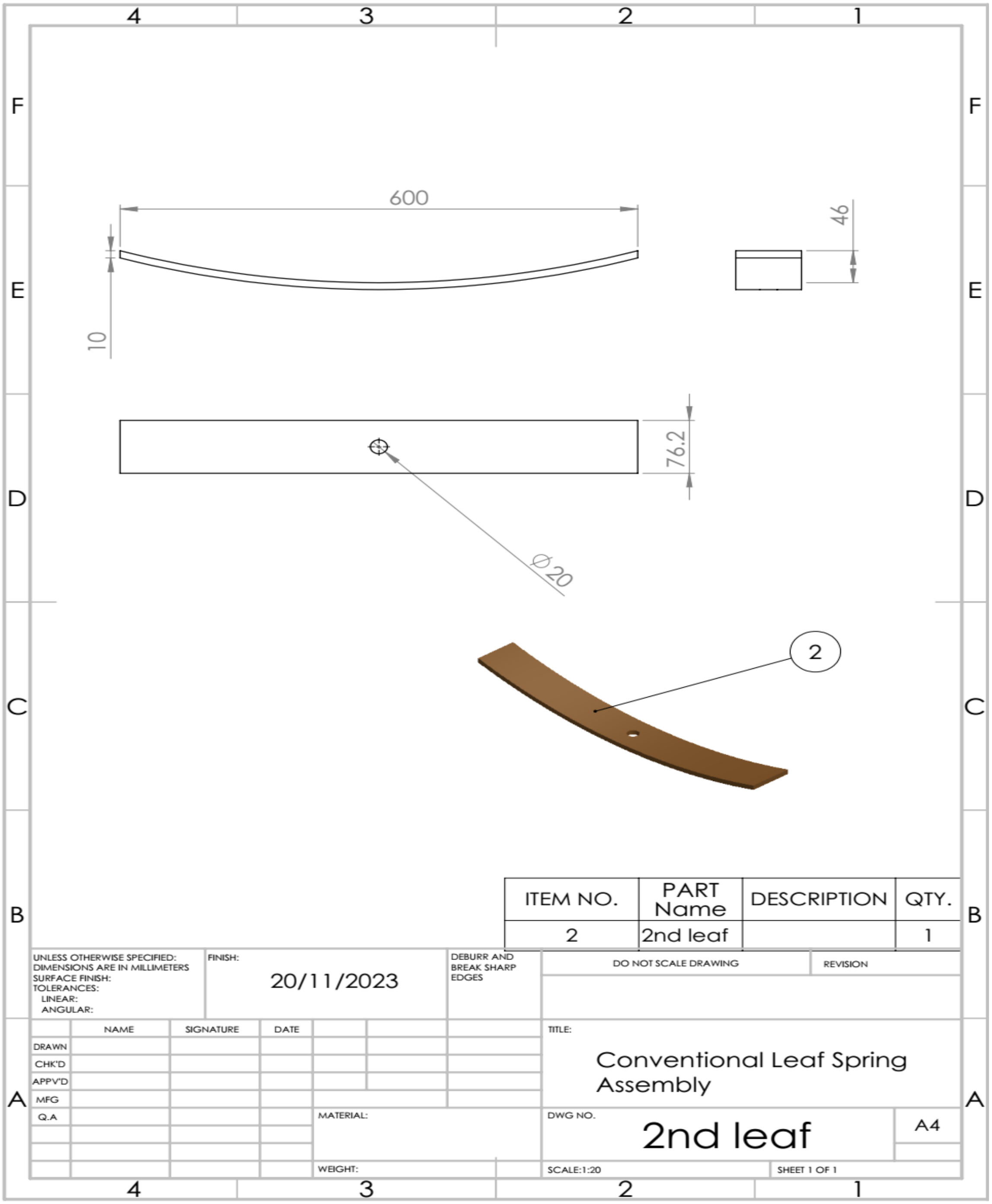
APPENDIX

Appendix I: Detail Drawing of Master Leaf of Conventional Leaf Spring



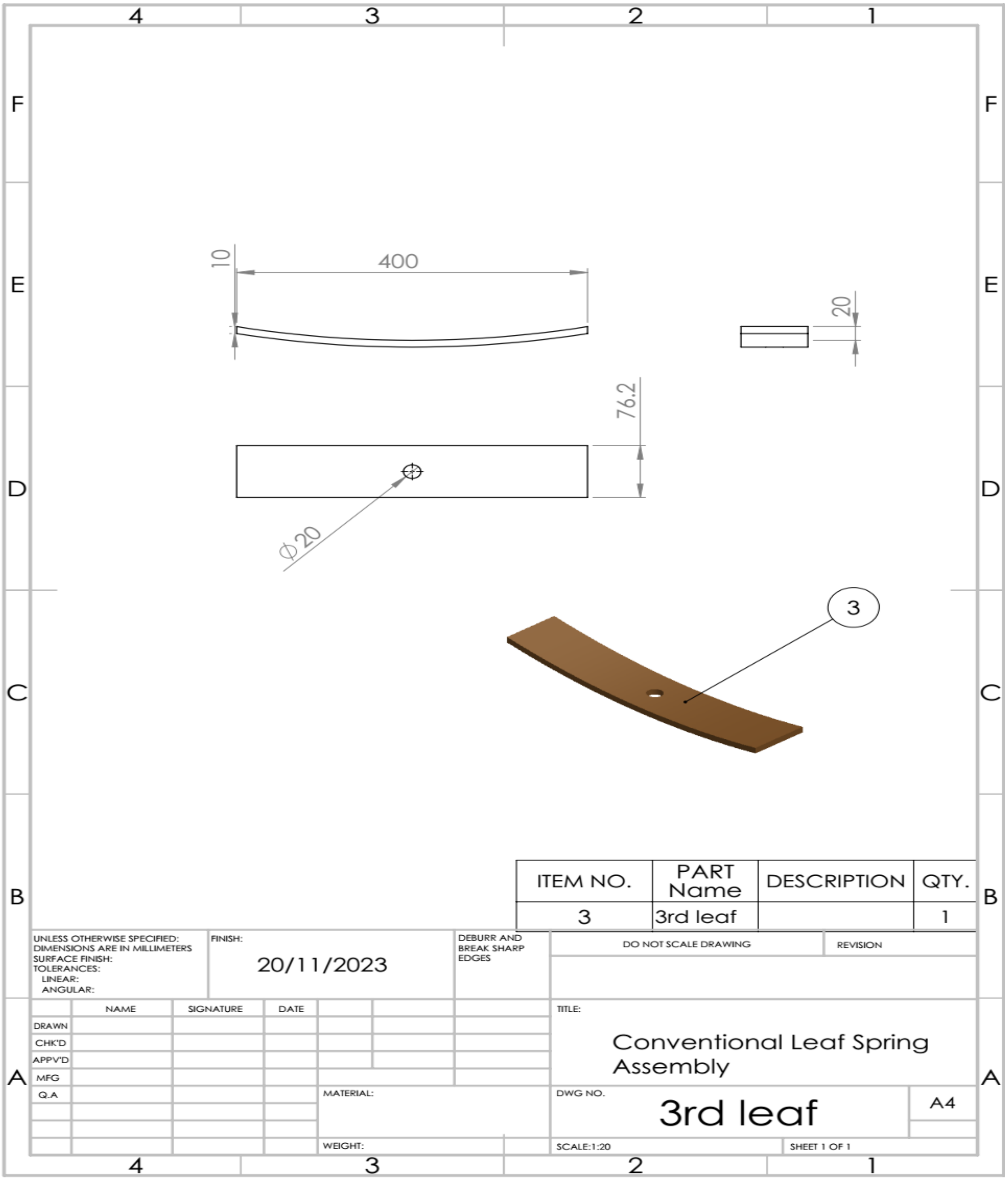
Appendix 1: Detail Drawing of Master Leaf of Conventional Leaf Spring

Appendix II: Detail Drawing of Second Leaf of Conventional Leaf Spring



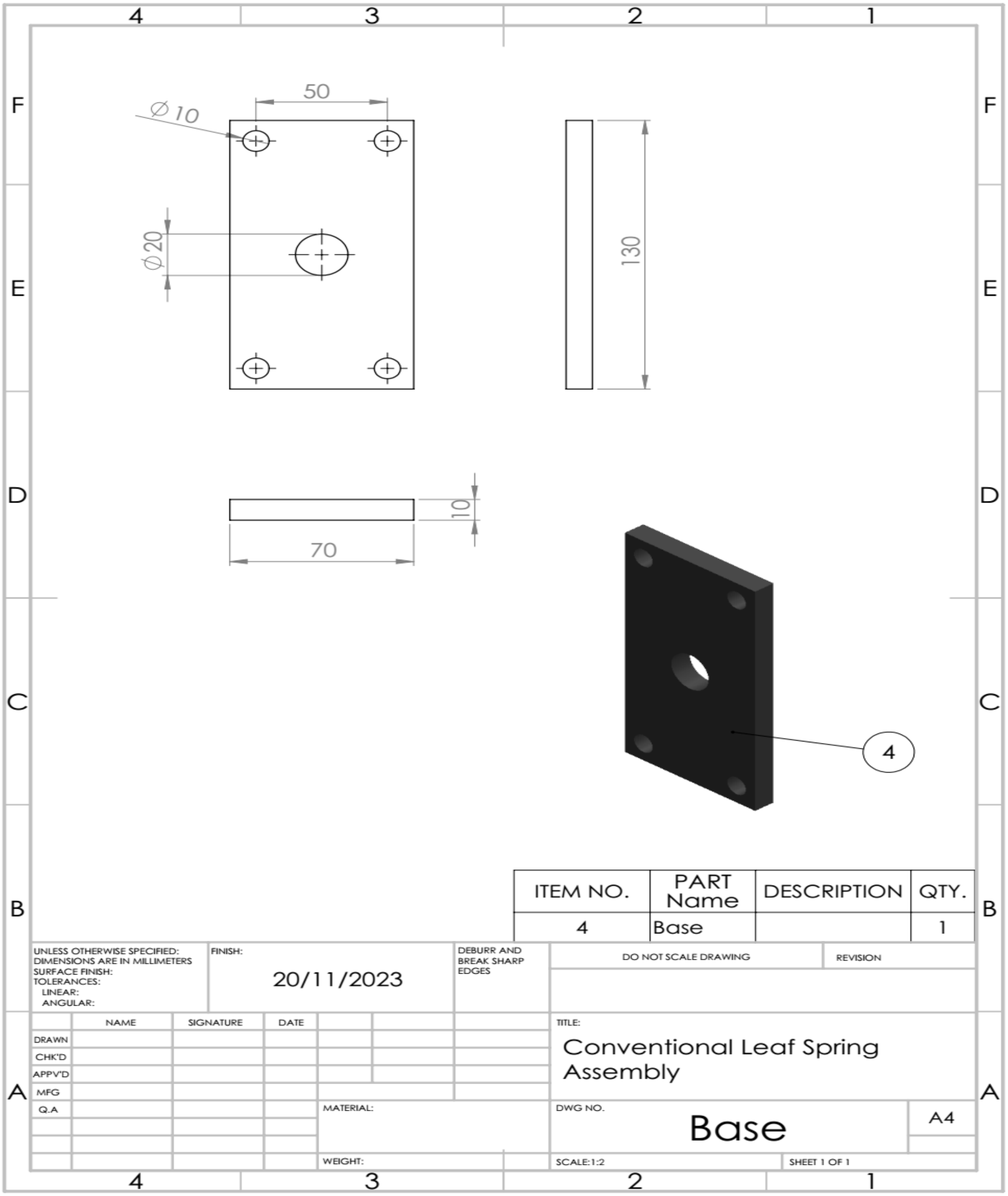
Appendix 2: Detail Drawing of Second Leaf of Conventional Leaf Spring

Appendix III: Detail Drawing of Third Leaf of Conventional Leaf Spring



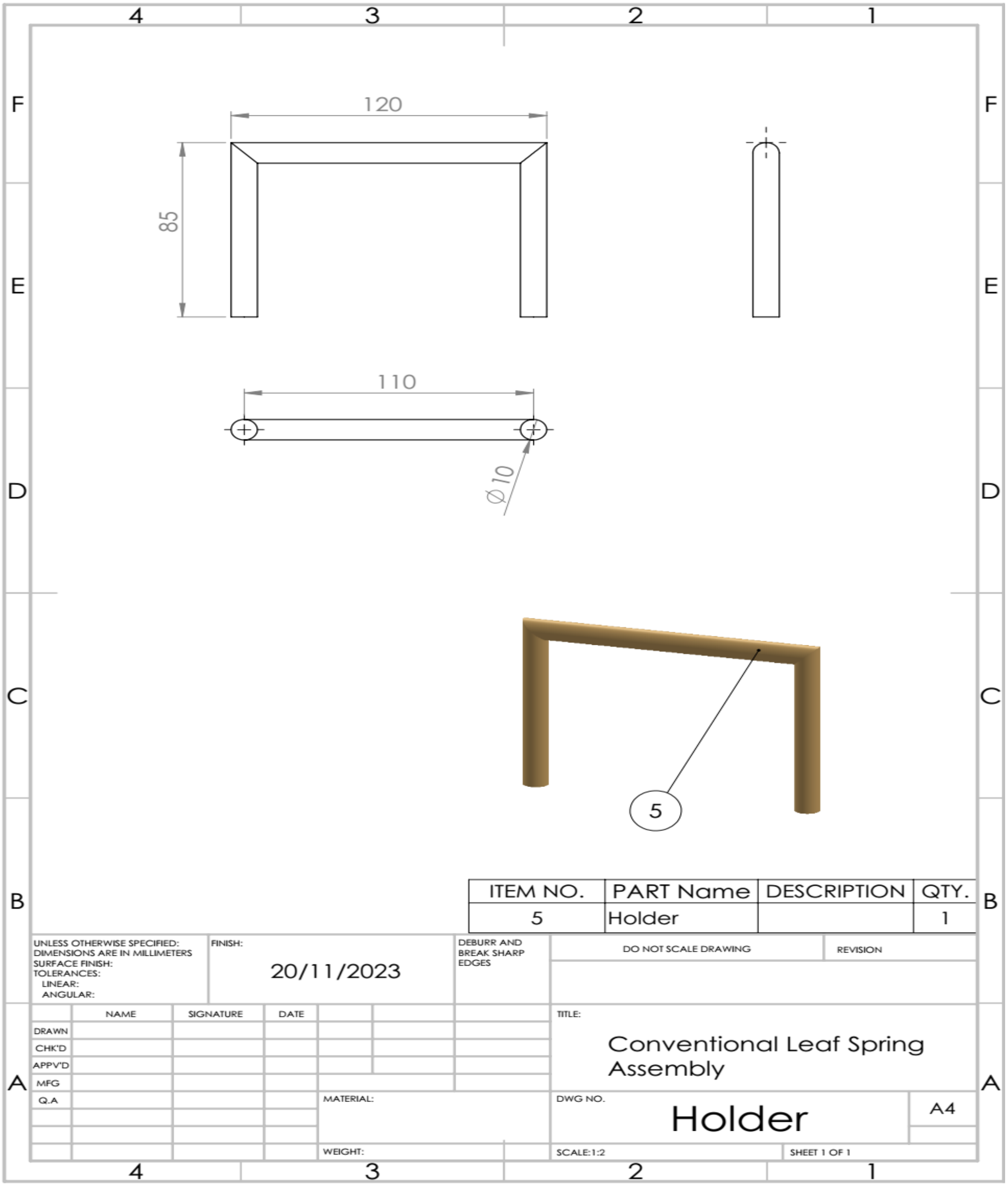
Appendix 3: Detail Drawing of Third Leaf of Conventional Leaf Spring

Appendix IV: Detail Drawing of Connector Base of Conventional Leaf Spring



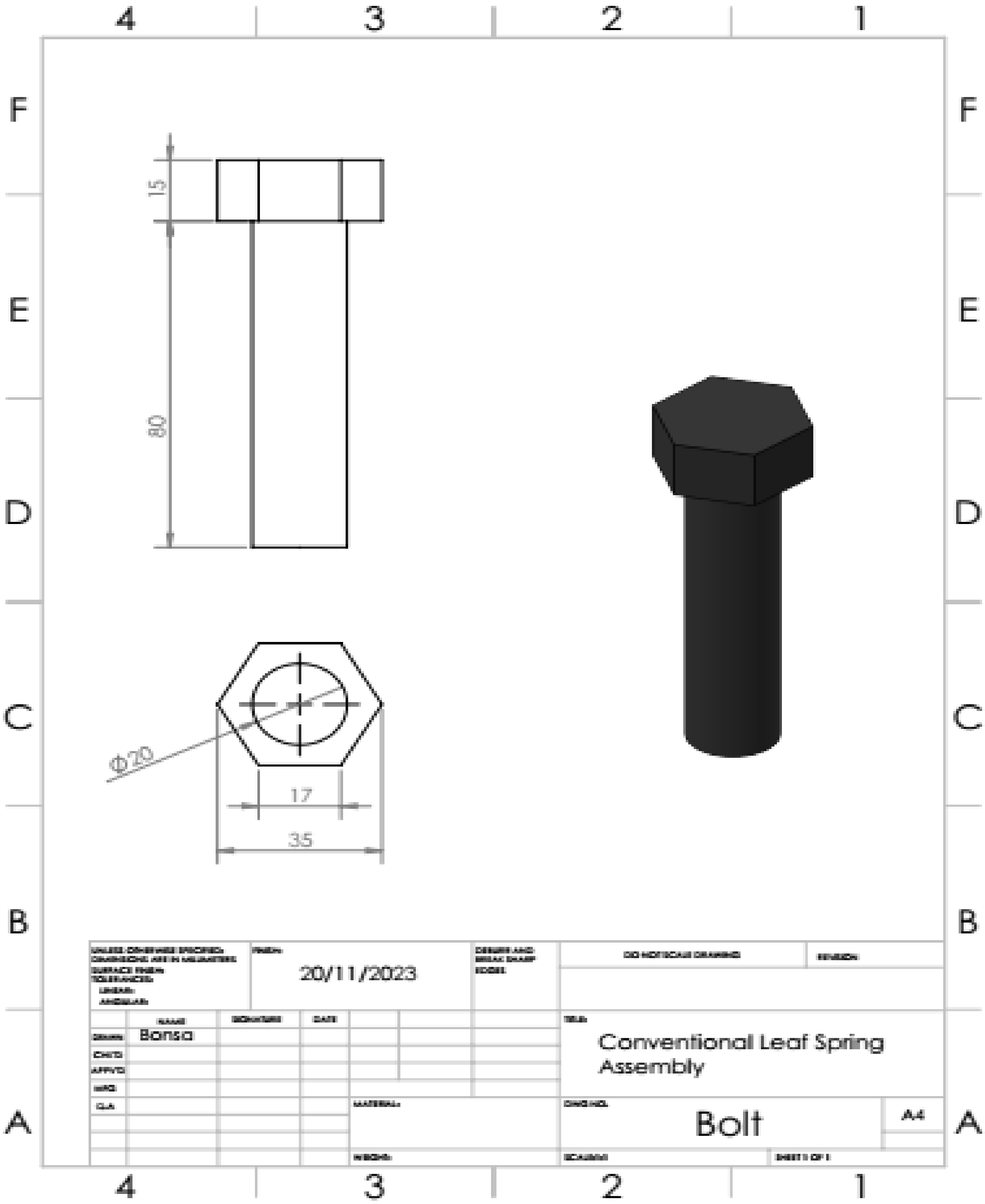
Appendix 4: Detail Drawing of Connector Base of Conventional Leaf Spring

Appendix V: Detail Drawing of Pin holder of Conventional Leaf Spring



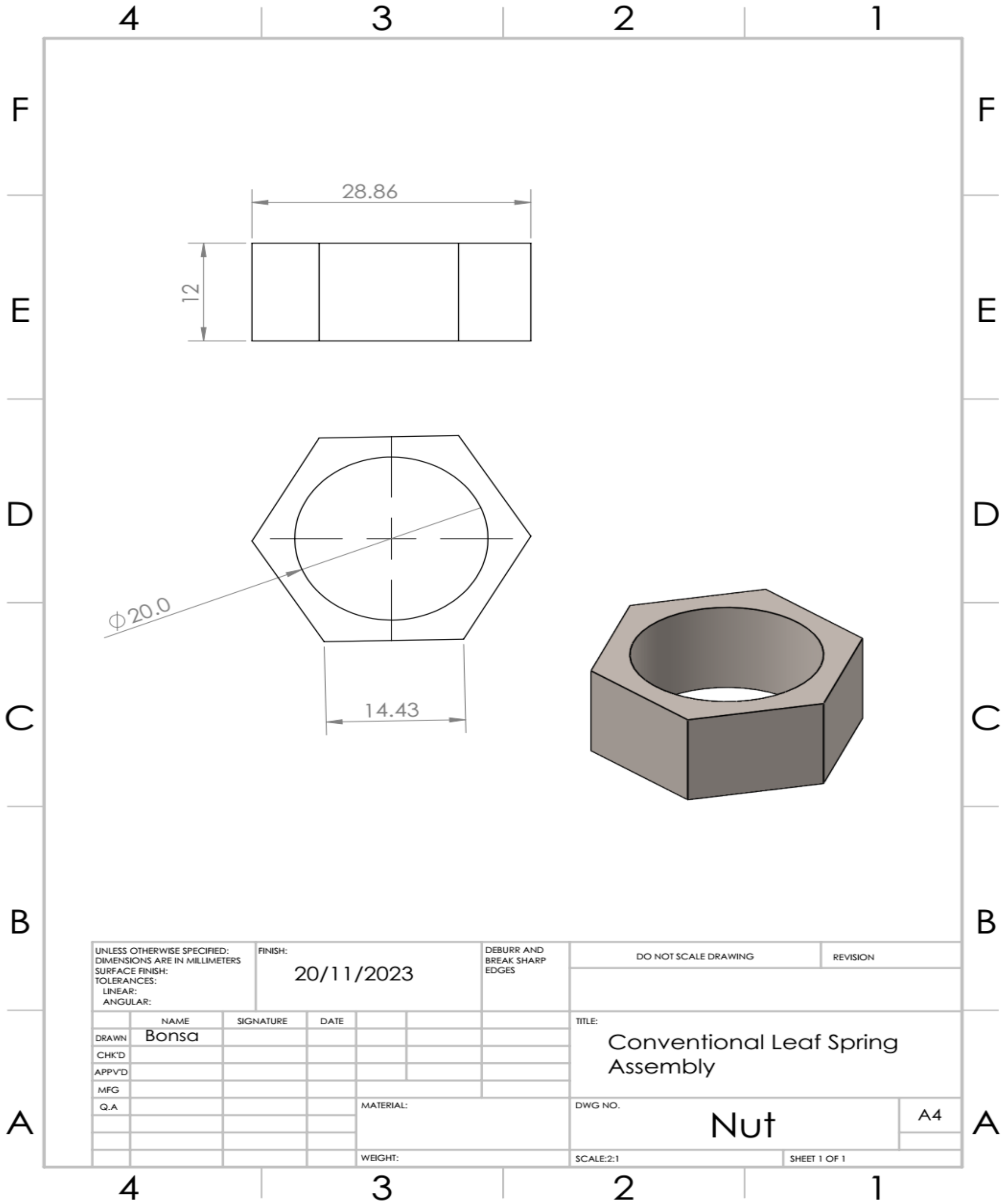
Appendix 5: Detail Drawing of Pin holder of Conventional Leaf Spring

Appendix VI: Detail Drawing of Bolt of Conventional Leaf Spring



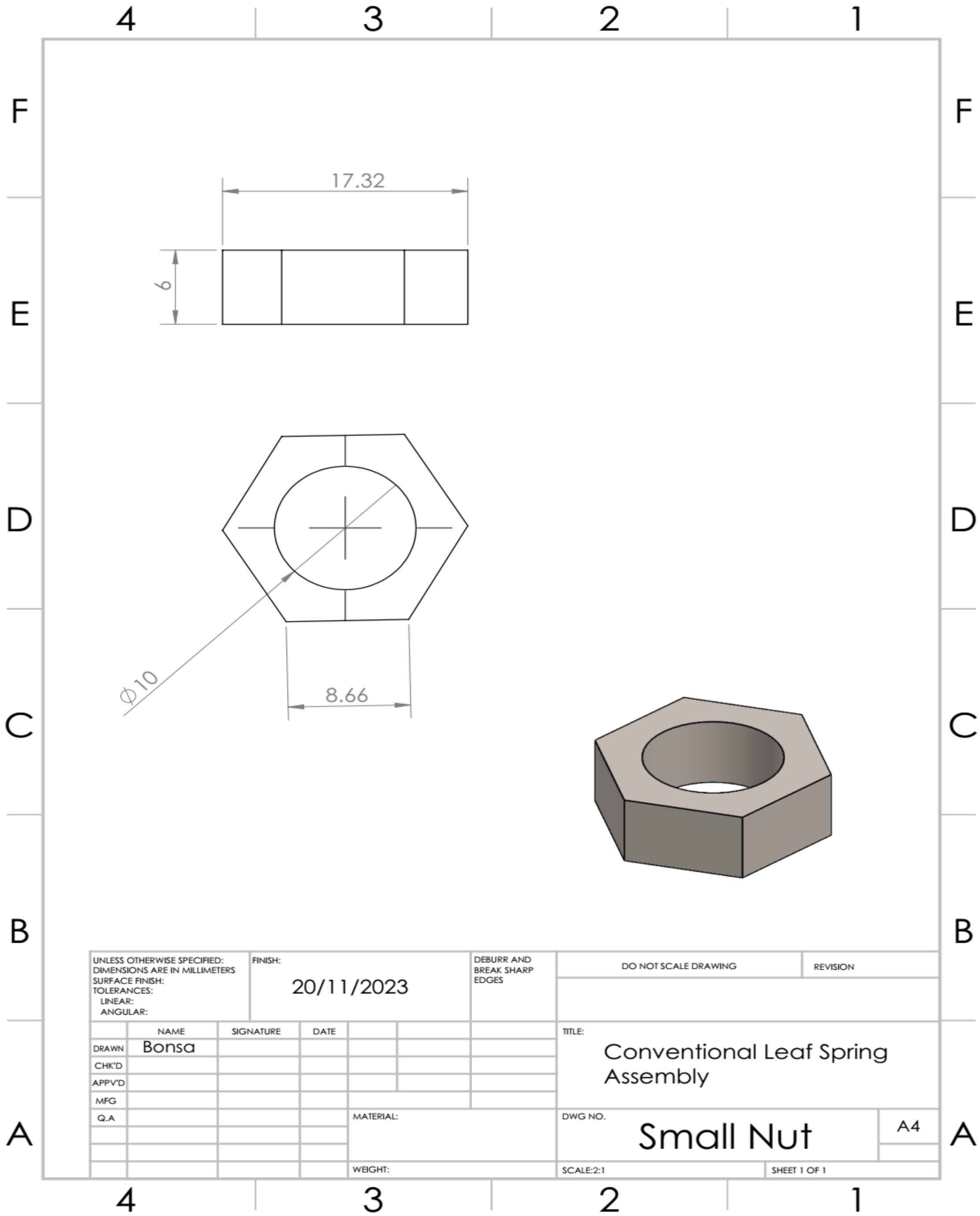
Appendix 6: Detail Drawing of Bolt of Conventional Leaf Spring

Appendix VII: Detail Drawing of Mid Nut of Conventional Leaf Spring



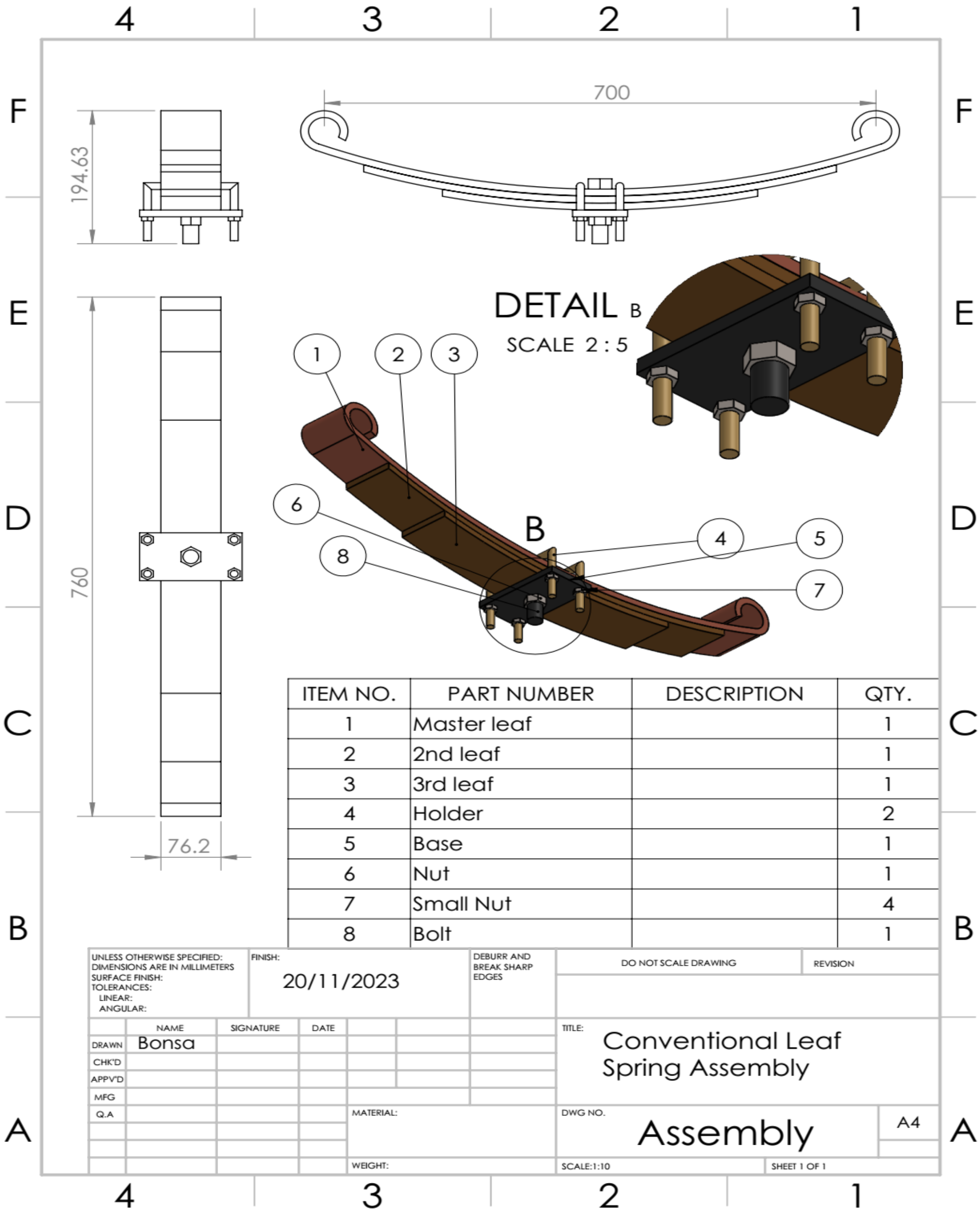
Appendix 7: Detail Drawing of Mid Nut of Conventional Leaf Spring

Appendix VIII: Detail Drawing of Small Nut of Conventional Leaf Spring



Appendix 8: Detail Drawing of Small Nut of Conventional Leaf Spring

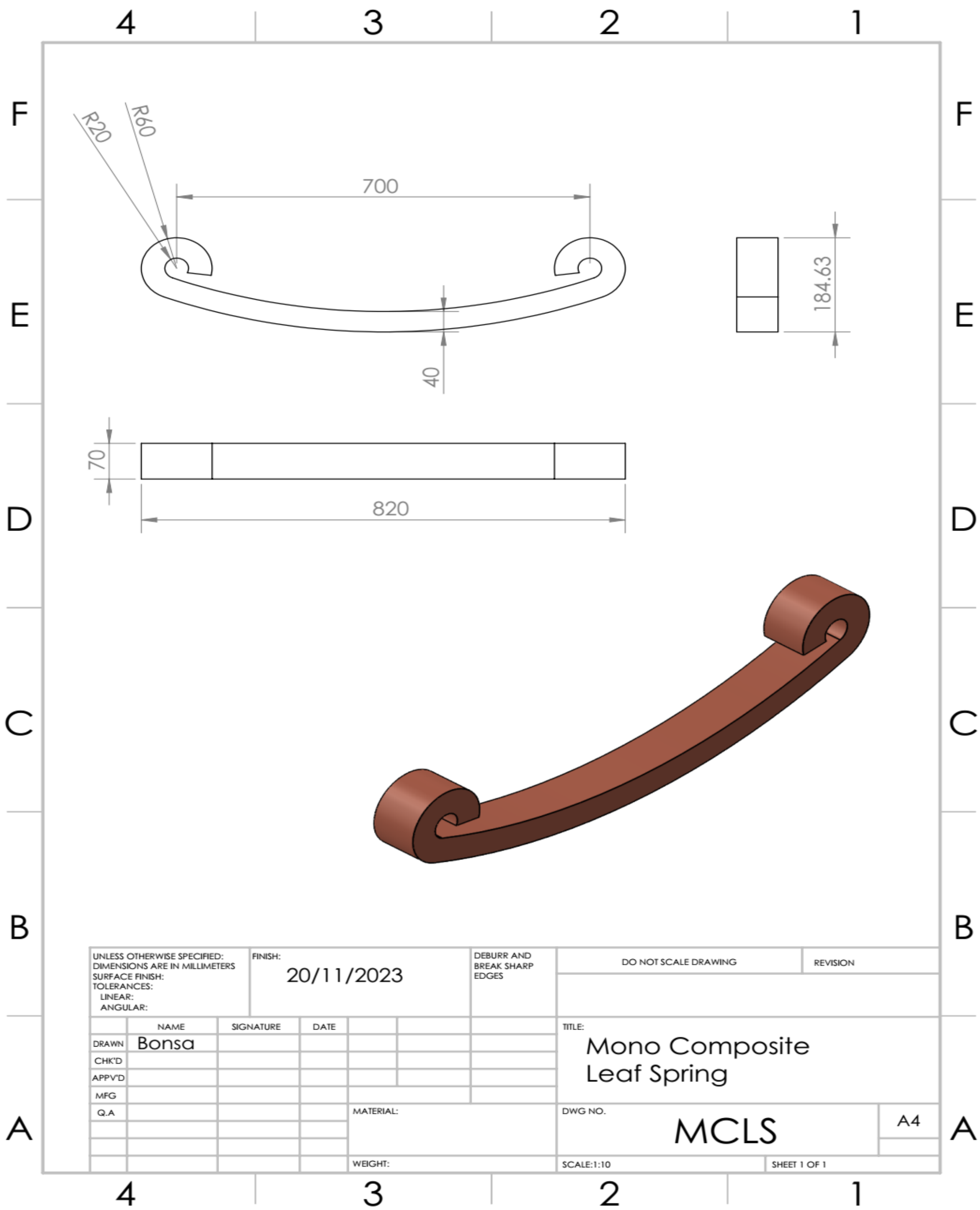
Appendix IX: Detail Drawing of Assembly of Conventional Leaf Spring



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Master leaf		1
2	2nd leaf		1
3	3rd leaf		1
4	Holder		2
5	Base		1
6	Nut		1
7	Small Nut		4
8	Bolt		1

Appendix 9: Detail Drawing of Assembly Nut of Conventional Leaf Spring

Appendix X: Detail Drawing of Mono Composite Leaf Spring



Appendix 10: Detail Drawing of Mono Composite Leaf Spring