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Finite Element Analysis of a Leaf Spring Manufactured Using Fused Deposition Modeling (FDM)

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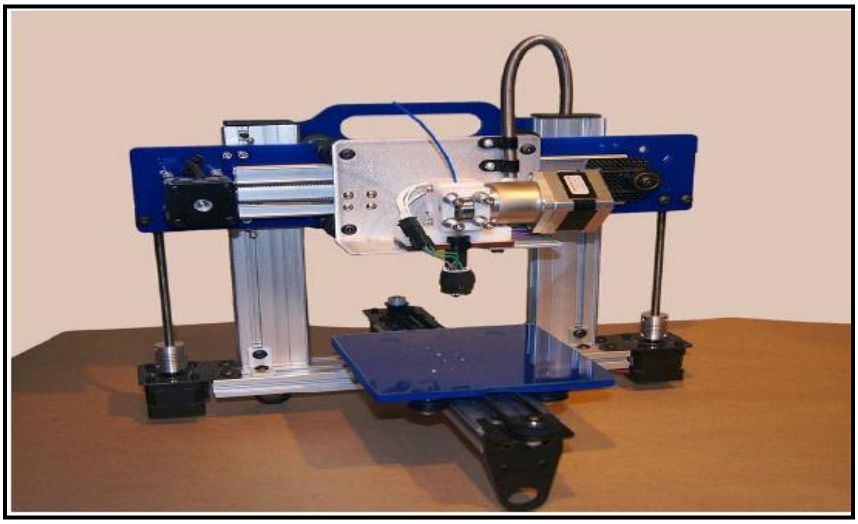
Abstract: This chapter will introduce fused deposition modeling (FDM), a prominent 3D printing technology. It will begin by presenting the fundamentals of additive manufacturing, highlighting its scientific principles and significance as an innovative and emerging industrial technology. The chapter will also discuss key parameters that influence polymer melt deposition and their interaction with the structural properties of components. Additionally, it will provide an overview of the quality characteristics of FDM-produced items in relation to process parameters. Additive manufacturing, as described, involves the layer-by-layer deposition of materials to create three-dimensional (3D) parts using various technologies. These materials may include composites, metals, polymers, or concrete. For a manufacturing process to qualify as an additive manufacturing method, it must involve three essential elements: creating 3D visual models using computer-aided design (CAD) tools such as AutoCAD, Solid Works, and CATIA, which may be either open-source or proprietary; proficient use of multiple operating systems by engineers or designers working on these tools; and the ability to generate intricate 3D product designs through CAD applications. Critical factors influencing the additive manufacturing process include the material consumption and the time required by the 3D printer to produce the final product.

Keywords: Leaf spring, composite material, Automobile suspension system, Finite element analysis.

1. Introduction: The automotive leaf spring suspension system holds significant potential for weight reduction, achieving approximately 10% to 20% improvement in weight efficiency. [1].By introducing composite materials, it is possible to lower the while maintaining structural integrity and performance. [2]Weight reduction plays a crucial role in energy efficiency for vehicle design, directly impacting fuel consumption. Composite materials, such as fiber-reinforced plastics (FRP), offer higher strength-to-weight efficiency and enhanced elastic strain energy absorption compared to steel, improving both fatigue resistance and durability.

[3]Leaf springs serve multiple functions in automotive applications, including suspension, shock absorption, and support for lateral loads, braking, and driving torque. Unlike helical springs, leaf springs can follow a guided path during deflection, acting both as structural components and energy absorbers. Using composite materials like FRP for weight reduction enhances vehicle ride quality without compromising stiffness or load capacity. Fatigue life assessment of leaf springs involves extensive practical testing, often requiring around 2-3 days to complete 100,000 fatigue cycles using a full-scale testing machine. Key factors influencing fatigue life include material properties, loading conditions, surface characteristics, size, and environmental factors, all of which must be meticulously considered.

[4]Engineers face the challenge of developing accurate and efficient methods for assessing fatigue life. While analytical and simulation techniques provide approximate results, they still require validation through physical testing.



FDM UNIT

Mono leaf springs are commonly used in light weight vehicles and those with lower load-carrying capacities. Advanced mono leaf springs are typically manufactured using glass fiber-reinforced polymers (GFRP), which are lightweight but have lower load-carrying strength compared to composites such as E-glass, S-glass, or carbon fiber.

[5]The objective of this project is to design and develop a mono leaf spring using advanced manufacturing techniques like fused deposition modelling (FDM). [6]The focus will be on designing and analyzing a mono leaf spring through a systematic approach. The concept of reverse engineering will be employed to measure all the design parameters of the existing mono leaf spring. Theoretical calculations will follow standard mono leaf spring design processes, and 3D modelling will be carried out using Solid Works software.

4.Objectives:-

- To find the load of composite (Epoxy, carbon) mono leaf spring using experimental testing.
- To Analyse the load on composite mono leaf spring by using FEA.
- To validate the load by using experimentally and FEA
- To validate the load on steel leaf spring and mono leaf spring by using FEA.

2.Material and properties of steel leaf spring :-

Properties	**Value**	**Unit**
Density (Kg/m^3)	7850	Kg/m^3
Tensile Strength	650	Mpa
Young's Modulus (MPa)	210000	Mpa
Elongation	8-25	%
Fatigue	475	Mpa
Yield strength	275	Mpa

3.Material and Properties of the E-Glass/epoxy.

Properties	Value
Tensile modulus along X-direction(Ex), Mpa	34000
Tensile modulus along Y-direction(Ey), Mpa	6530
Tensile modulus along Z-direction(Ez), Mpa	6530
Tensile strength of the material , Mpa	900
Compressive strength of the material ,Mpa	450
Shear modulus along XY-direction (Gxy),Mpa	2433
Shear modulus along YZ-direction (Gyz),Mpa	1698
Shear modulus along ZX-direction (Gzx),Mpa	2433
Poisson's ratio along XY-direction (NUxy)	0.217
Poisson's ratio along YZ-direction (NUyz)	0.366
Poisson's ratio along ZX-direction (NUzx)	0.217
Mass density of the material	2.610
Flexural modulus of the material, Mpa	40000
Flexural strength of the material, Mpa	1200

5.(Finite Element Analysis):-

Finite Element Analysis (FEA) is a computational technique used to simulate and analyse real-world systems. It works by dividing a structure into smaller, manageable elements, assigning equations to each, and solving them simultaneously to predict the system's overall behaviour. This approach is especially beneficial for analysing complex geometries, diverse loads, and materials where precise analytical solutions are challenging to achieve. FEA is widely applied in structural, thermal, and fluid analysis but can also be extended to other types of simulations.

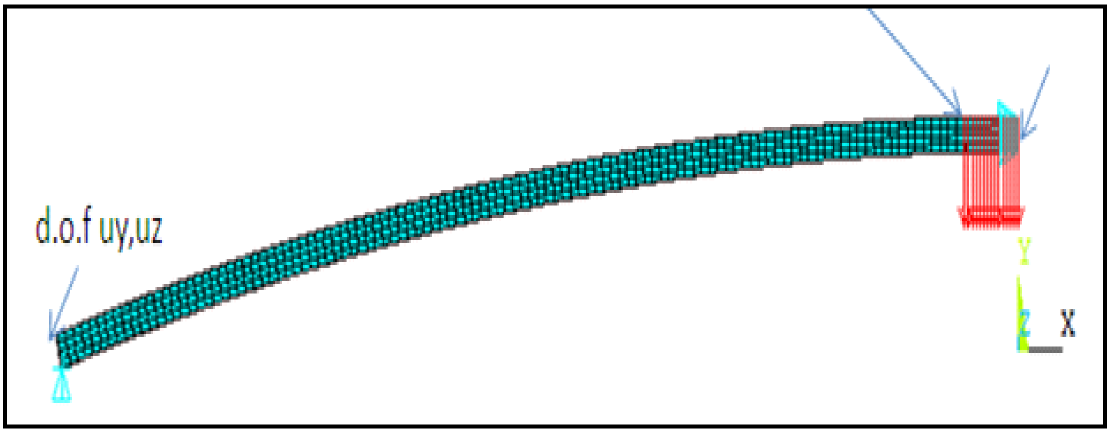


Figure 2: Leaf Mounting Position in ANSYS.

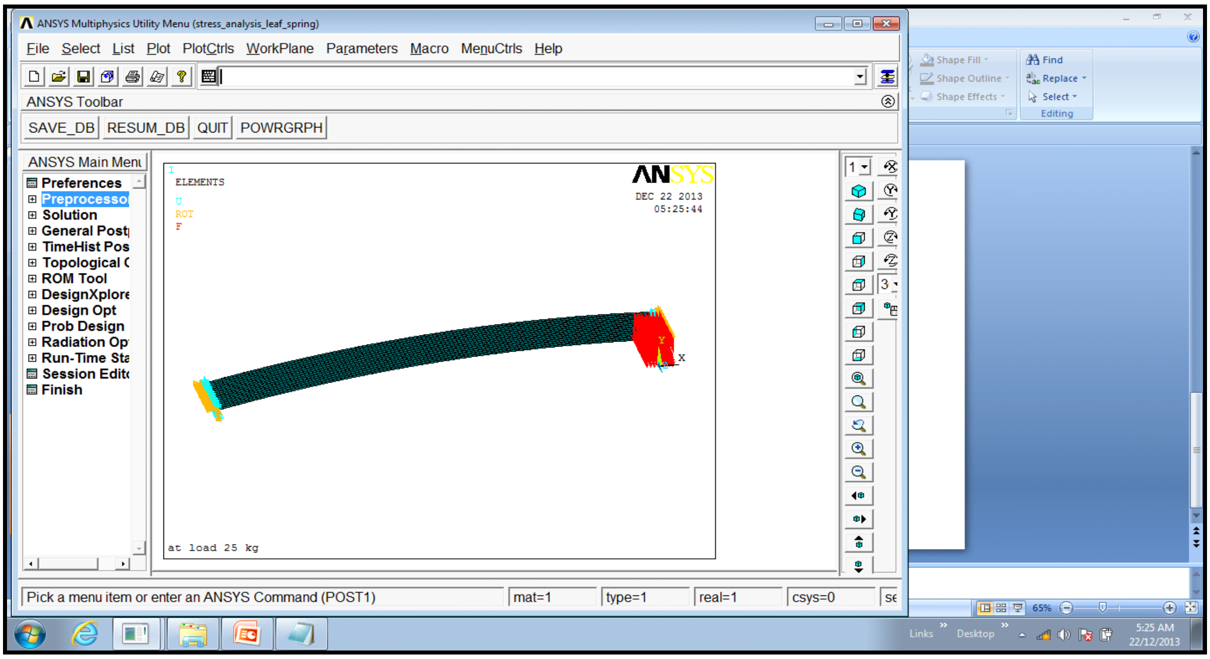
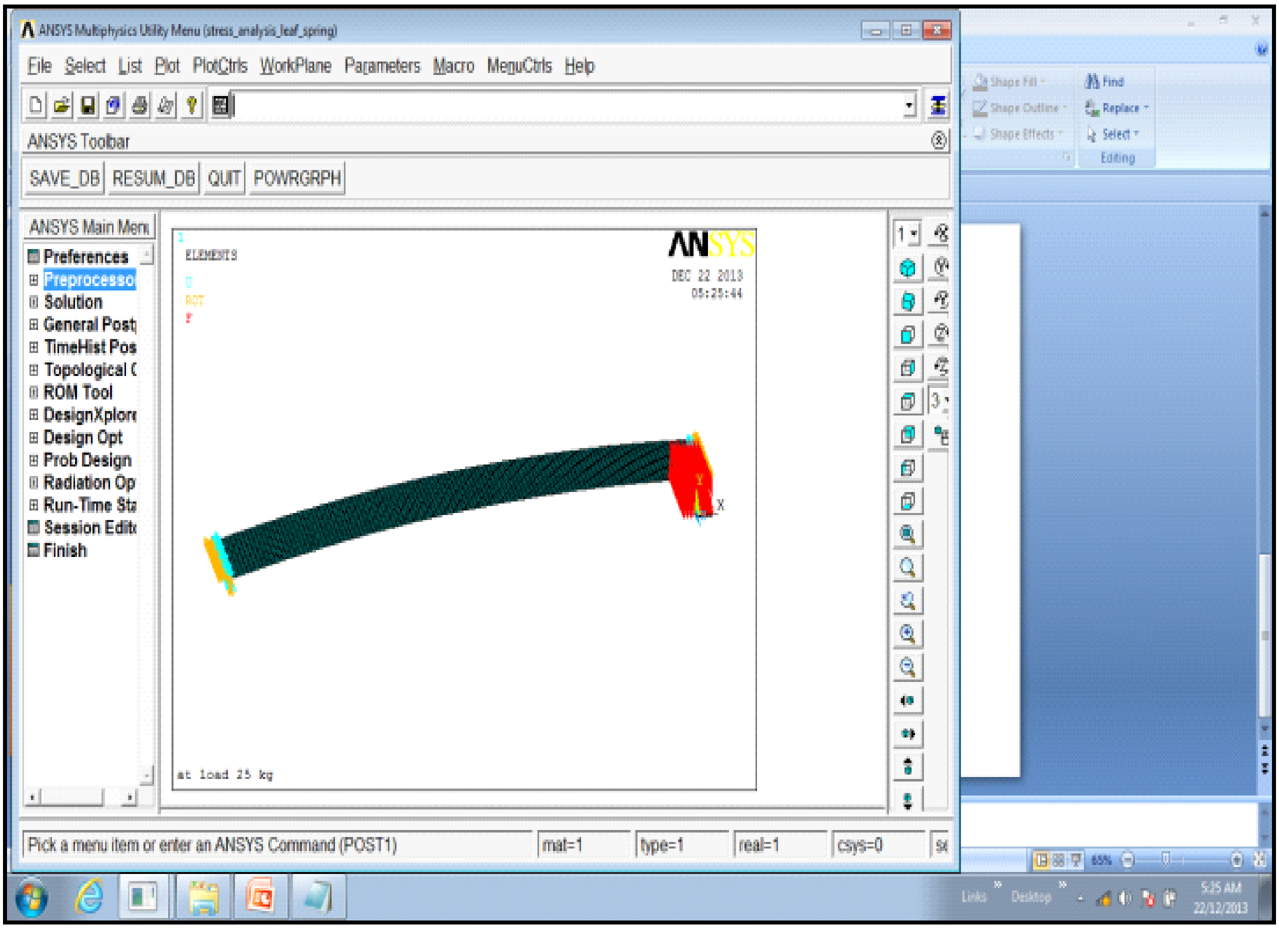
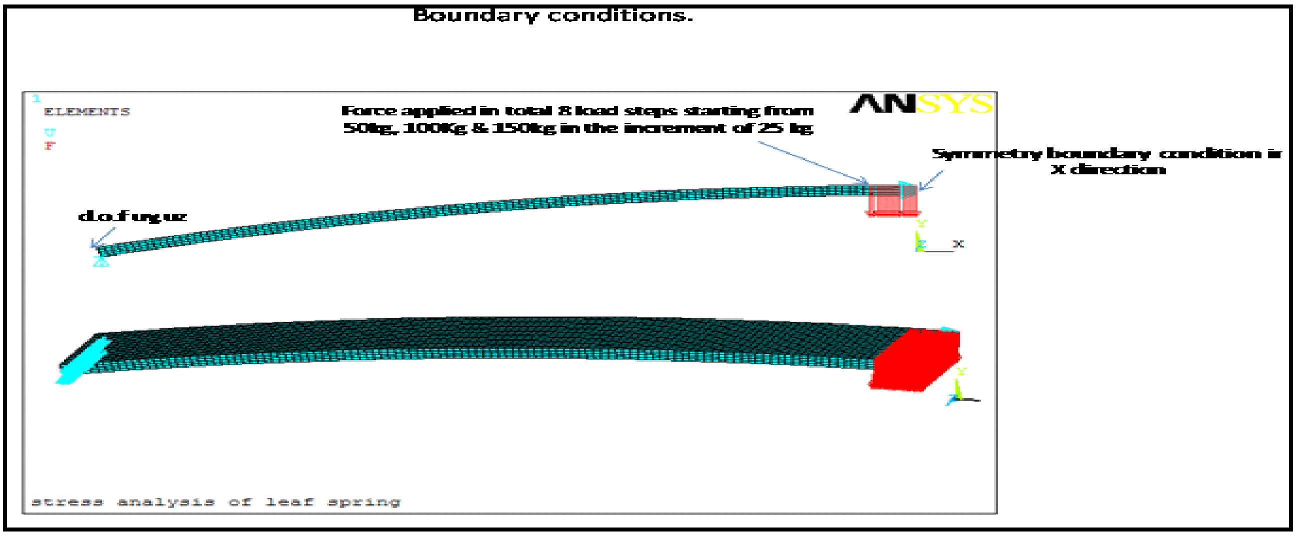


Figure 3: FE model of Leaf spring.





Boundary Condition at Leaf spring.

1 . Develop computer simulations or CAD representations for structures, products, components, or systems.

2. Evaluate performance by simulating operational loads and design conditions.

3. Investigate physical behaviors' such as stress distribution, thermal variations, or electromagnetic effects.

4. Refine designs during early development to lower manufacturing expenses.

5. Perform prototype testing in controlled or inaccessible environments, such as in biomedical application.

6.Result and discussion:-

1.Stress Distribution for load of 50kg

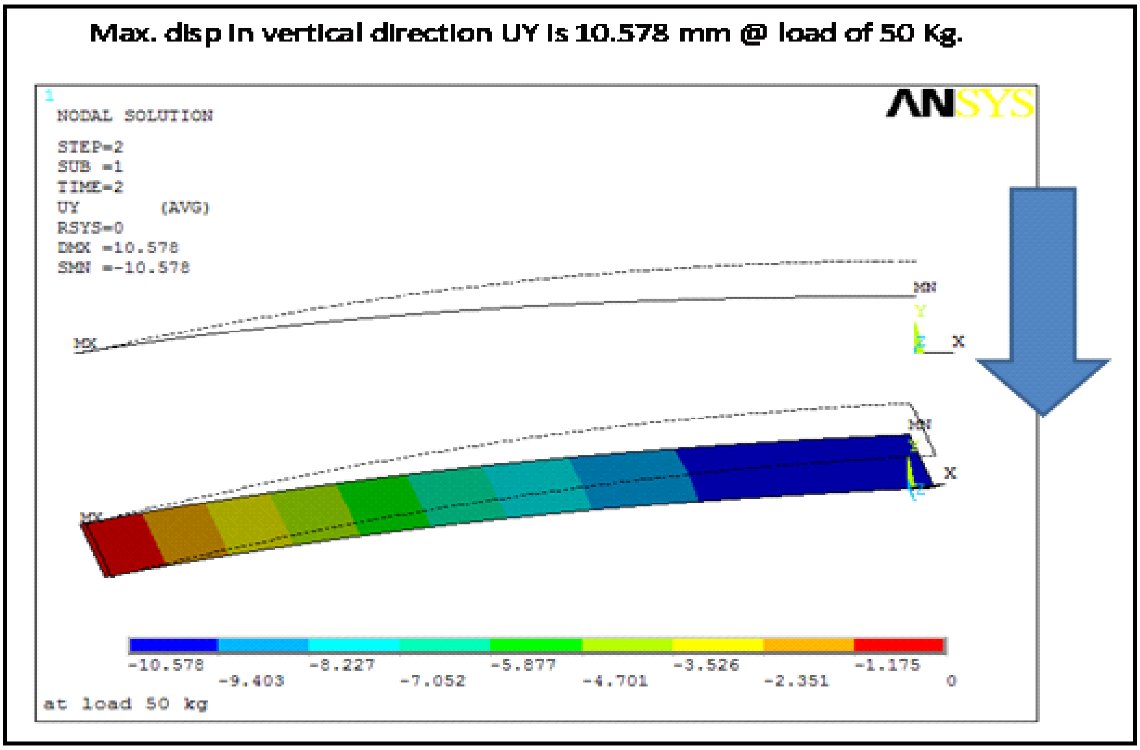


Figure 5 : Deflection in Y -Direction.

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2.Stress Distribution for load of 100kg.

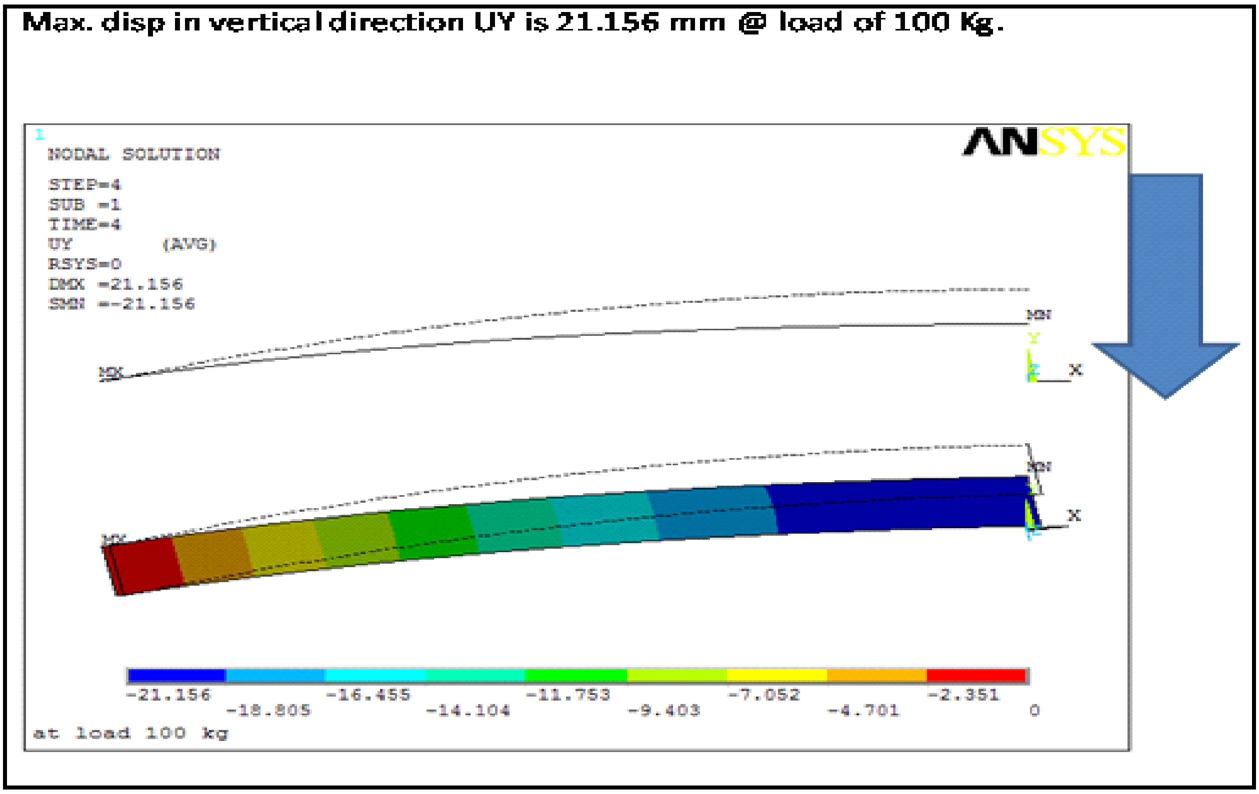


Fig. Deflection in Y -Direction.

3.Stress Distribution for load of 150kg.

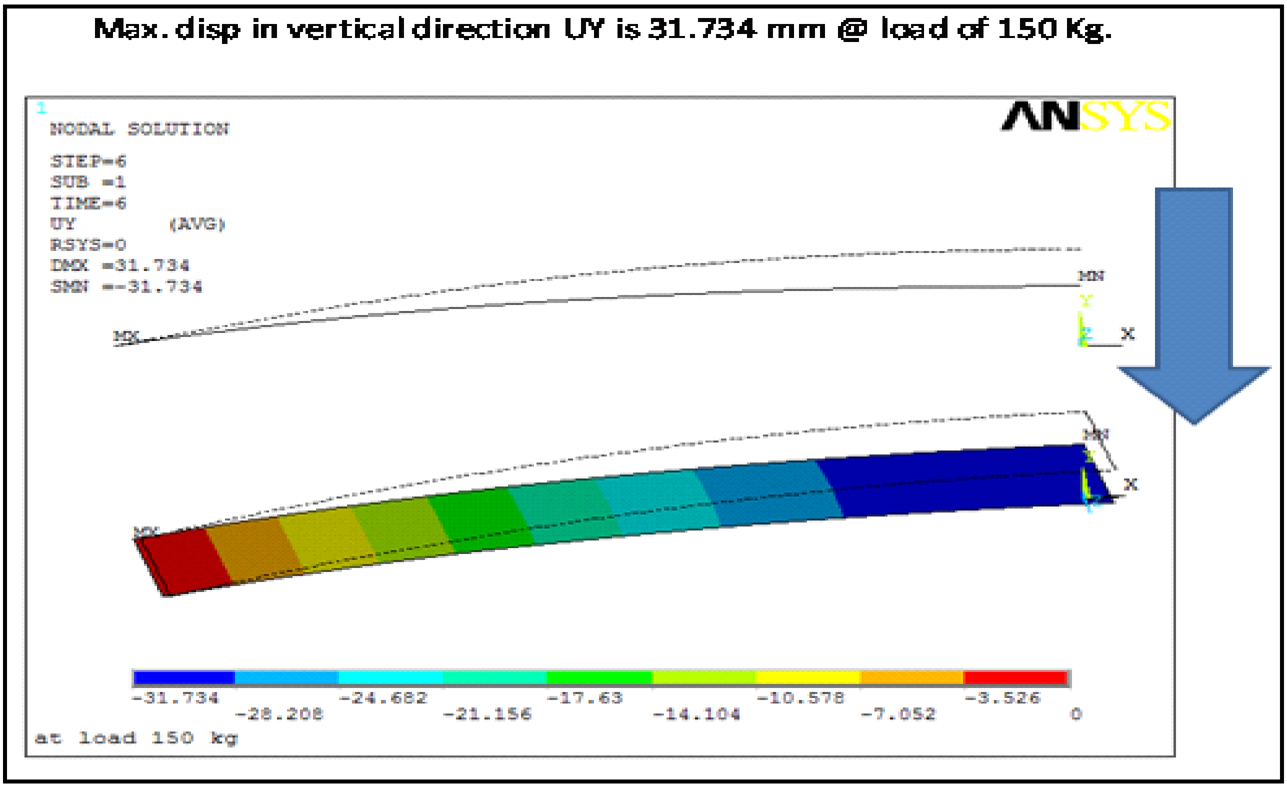
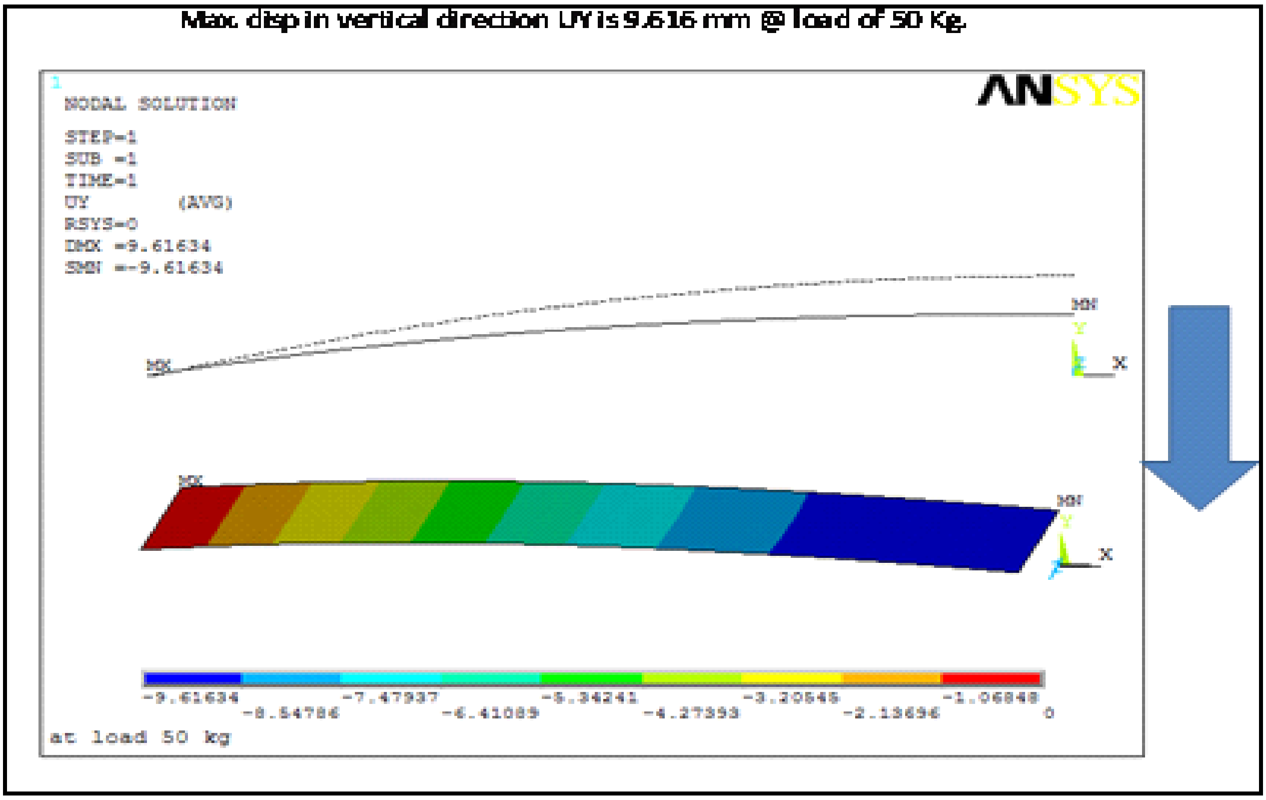
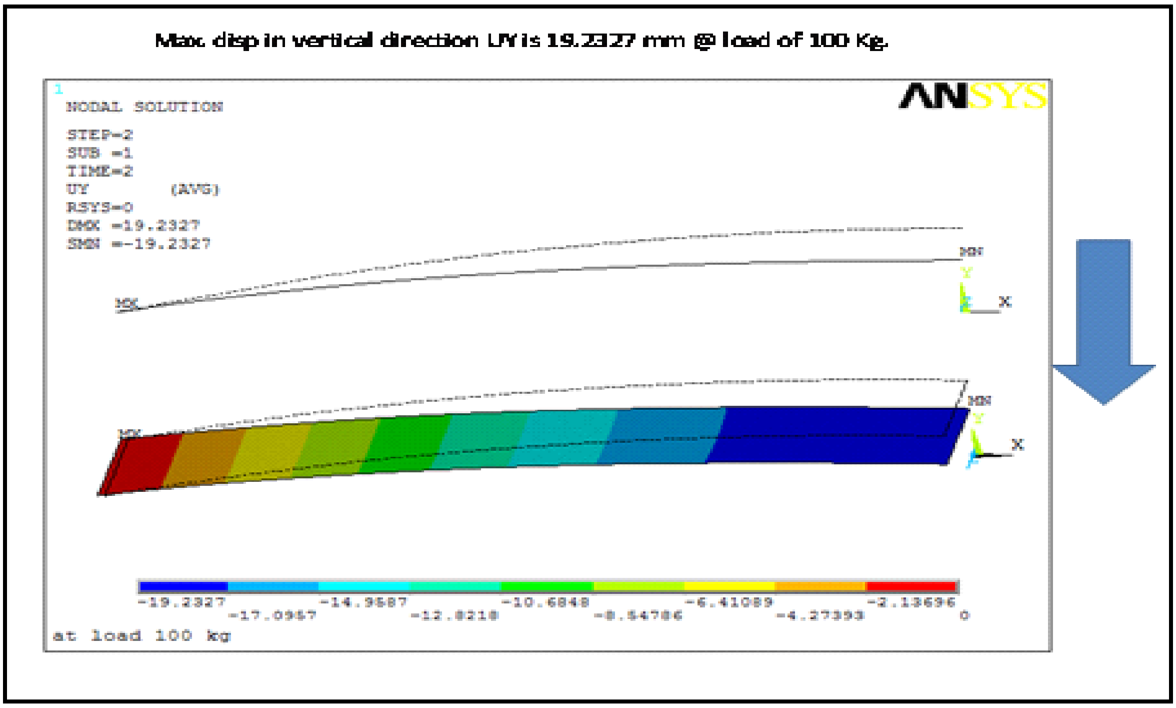


Figure 4: Deflection in Y -Direction



1.Maximum Disp. at vertical direction 50kg.

2.Maximum Disp. at vertical direction 100kg.



3. Maximum Disp. at vertical direction150kg.

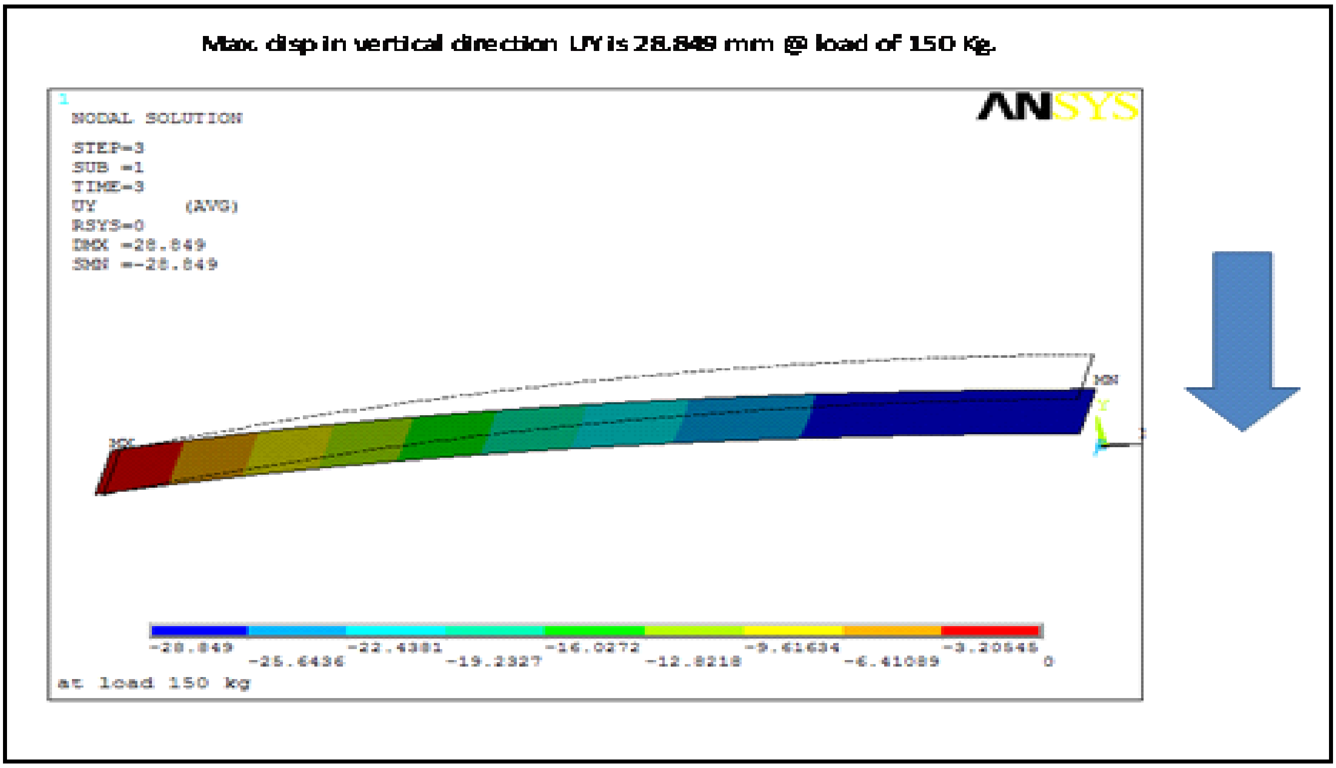


Table 2:Result's and validations:-

1. Comparison of vertical deflection due to loading on fdm leaf spring with steel leaf spring through ANSYS.

SN	VERTICAL LOAD BY UTM IN KG	VERTICAL DEFLECTION IN STEEL LEAF SPRING IN MM	VERTICAL DEFLECTION IN FDM LEAF SPRING IN MM	%DIFFERNCE IN DIFLECTION
1	50	10.5	9.62	8
2	100	21.15	19.23	9
3	150	31.7	28.84	9

9.Experimentation of loading deflection By UTM.

The FDM leaf was made for UTM testing based on the leaf spring dimensions of a Maruti 800 car. FEM results were validated using the UTM. The following steps are followed for test validation.

- The setup sequence was completed with the UTM.
- The measurement point was selected.
- Deflection was measured under defined loading conditions.

- Load/deflection values obtained from FEM analysis were compared with the values obtained from testing and UTM for carbon fiber plate specimens.
- The Load/deflection values obtained from FEA analysis for the FDM plate and steel plate were compared.

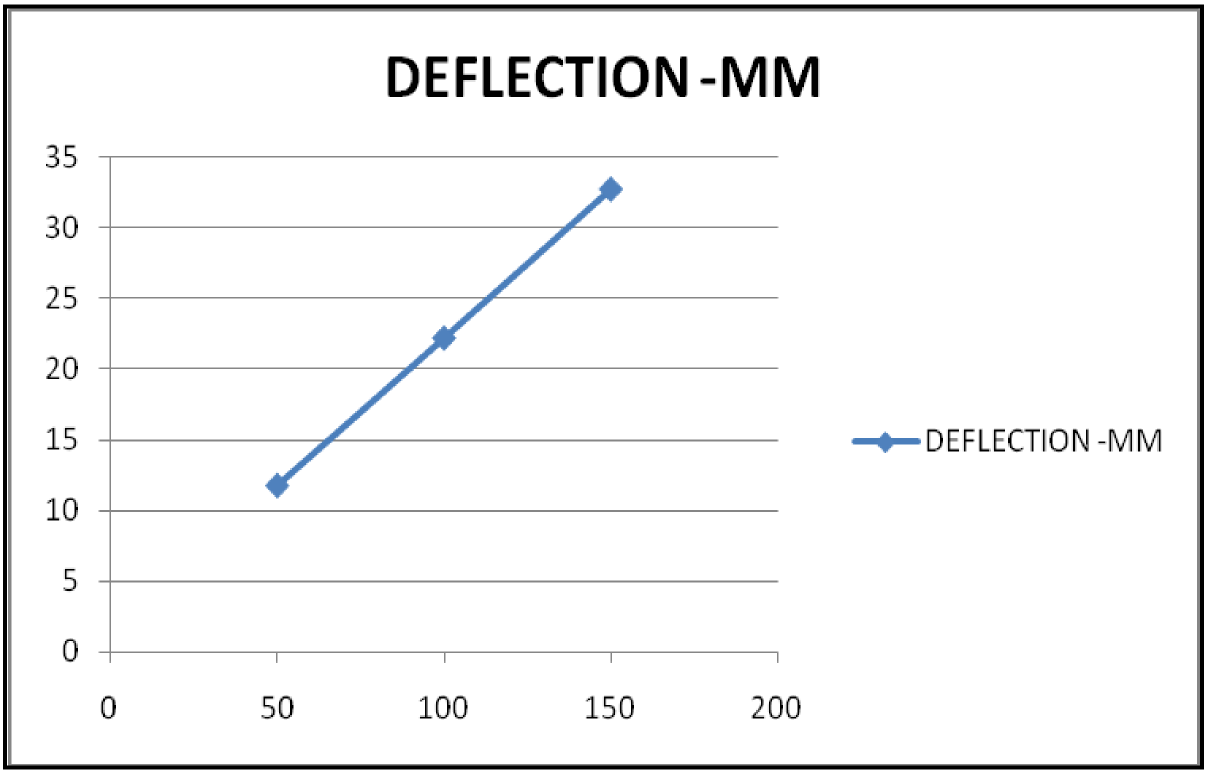


Figure 5: Graphical Representation of FDM leaf.

figure 6:- Loading and deflection experimentation of carbon fiber leaf at UTM.

10.Observation Table :-

SN	VERTICAL LOAD BY UTM IN KG	VERTICAL DEFLECTION IN STEEL LEAF SPRING IN MM	VERTICAL DEFLECTION IN fdm LEAF SPRING IN MM	% DIFFERNCE IN DIFLECTION
1	50	10.5	9.62	8
2	100	21.15	19.23	9
3	150	31.7	28.84	9

Table 1:- Comparison of vertical deflection due to loading on fdm leaf spring with steel leaf spring through ANSYS

11.Observation Table:-

SN	LOAD IN KG	DEFLECTION IN MM BY UTM	DEFLECTION IN MM	DIFFERENCE IN %
1	50	10.4	9.62	7.5%
2	100	20.2	19.23	6%
3	150	30.7	28.84	5%

Table 2 :- Showing comparison of experimental & FEM results of loading &deflection of Fdm leaf spring.

12.Observation Table:-

LOAD IN KG	DEFLECTION IN VERTICAL DIRECTION MM		DEFLECTION IN HORIZONTAL DIRECTION MM		VON MISSES STRESS	
	FDM LEAF	STEEL LEAF	FDM LEEAF	STEEL LEAF	FDM LEEAF	STEEL LEAF
50	9.2	10.5	1.5	1.7	117	117
100	19.23	21.15	3.15	3.4	235	235

150	**28.84**	**31.7**	**4.7**	**5.2**	**353**	**353**

Table 3 :- Comparison of FEA results of loading on fdm leaf & steel leaf.

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