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"Structural, Modal and Buckling Analysis of Composite Material and Weight Reduction of Drive Shaft"

Rajesh Anawal[1], G. S. Lamani[2],
[1](*Assistant Professsor Mechanical Department, SDMCET Dharwadvtu, Karnataka, India)*
[2](*Assistant Professor, Mechanical Department JSPM Narhe Technical Campus/SPPU Pune, India)*

Abstract *Replacing A Composite Material For Conventional Metallic Material Has Many Advantage Like Higher Specific Stiffness, Strength Of The Composite Material. In This Work Replacement Of 2-Piece Steel Drive Shaft Was Made With Single-Piece Aluminium Alloy, And High Strength Carbon And Epoxy & High-Modulus Carbon And Epoxy Composite Drive Shaft For Which Are Used In Automotive Application. Design Parameter Were Optimized With An Objective Of Minimizing The Weight Of Composite Drive Shaft. The Design Optimization Also Shows The Significant Potential Improvement In The Performance Of Drive Shaft.*

Keywords:- *Torsional Buckling Capacities, Torque Transmission Capacity, Fundamental Lateral Natural Frequency, Buckling Analysis, Ansys Workbench.*

I. Introduction

Fuel Used In Automobile Like Petrol, Diesel Are Non-Renewable Source Of Energy. So, Main Intention In Automobile Is To Increase Mileage Of Vehicle. A Way To Increase The Mileage Of Vehicle Is By Reducing Vehicles Weight. A Variety Of Alternative Are Being Explored By The Automobile Company, There Is More Than One Possible Answer. At This Point The Only Certainty Is That No Single Material Or Type Of Material Will Dominant. The Biggest Question An Automotive Industry Face Is, Which Material Should Be Used, To Reduce The Weight Of The Vehicle & Save Fuel. All Automobile Companies, Which Correspond To Design With Rear Wheel Drive & Front Engine Installation, Have Transmission Shaft. An Automotive Drive Shaft Transmit Power From Engine To Differential Gear Of A Rear Wheel Drive Vehicle. Weight Reduction Of The Drive Shaft Has Certain Role In The General Weight Reduction Of The Vehicle & Can Be A Highly Desirable Goal, If It Can Be Achieved Without Increase In Cost & Decrease In Quality. The Material Which Is Being Used Today Is High Strength Steel. Metallic Drive Shaft Have Limitation In Weight & Has Low Critical Speed. Fundamental Lateral Natural Frequency Of A Shaft Is Inversely Proportional To The Square Of Beam Length And Proportional To The Square Root Of Specific Modulus.

The Torque Capacity Of The Drive Shaft For Passenger Cars Should Be Larger Than 3500 Nm & The Fundamental Lateral Natural Frequency Should Be Higher Than 6500 Rpm To Avoid Whirling Vibration. Since Fundamental Lateral Natural Frequency Of A One-Piece Drive Shafts Made Of Steel Or Aluminum Is Normally Lower Than 5700 Rpm. When The Length Of The Drive Shaft Is Around 1.5 M, The Steel Drive Shaft Is Usually Manufactured In Two Pieces To Increase The Fundamental Bending Natural Frequency. Polymer Matrix Composites Are Most Common Composite Material Being Used In Drive Shaft. The Most Common Are Carbon Epoxy, Glass Epoxy And Carbon/Glass Epoxy Hybrids. The Advanced Composite Materials Such As Graphite, Carbon And Glass With Suitable Resins Are Widely Used Because Of Their High Specific Strength (Strength/Density) And High Specific Modulus(Modulus/Density).Substituting Composite Structures For Conventional Metallic Structures Has Many Advantages Because Of Higher Specific Stiffness And Strength Of Composite Materials. Since, Carbon Fiber Epoxy Composite Materials Have More Than Four Times Specific Stiffness Of Steel Or Aluminum Materials, It Is Possible To Manufacture Composite Drive Shafts In One-Piece Without Reducing Whirling Vibration Over 6500 Rpm. The Two-Piece Steel Drive Shaft Consists Of Three Universal Joints, A Center Supporting Bearing And A Bracket, Which Increases The Total Weight Of An Automotive Vehicle. In Addition, The Use Of Single Torque Tubes Reduces Assembly Time, Inventory Cost, Maintenance, And Part Complexity. Analytically It Was Proved That Composite Drive Shaft Has Many Benefits Such As Reduced Weight And Less Noise And Vibration. But Experimental Investigations Regarding Performance Of Composite Drive Shaft Have Not Done To Compare With Conventional Steel Drive Shaft. To Decrease The Bending Stresses Various Stacking Sequences Can Be Used. By Doing The Same, We Can Maximize The Torque Transmission, Static Torque Capability, Buckling Torque Capability And Bending Natural Frequency. The Objective Of This Work Is, To Analyze The Comparative Performance Of Carbon Epoxy Composite Drive Shaft With Respect To Conventional Steel Drive Shaft For Torque Transmission Capability. By Analyzing Performance Conventional Two Piece Steel Drive Shaft Can Be Replaced By One Piece Composite Drive Shaft

II. Theoretical Background

All The Automobiles, Which Correspond To Design With Front Engine Installation And Rear Wheel Drive, Have Transmission Shafts. An Automotive Propeller Shaft Transmits Power From The Engine To The Differential Gear Of A Rear Wheel Drive Vehicle.

2.1 Function Of Drive Shaft:

1. It Should Transmit Torque From The Engine Transmission To The Differential Gear Box.
2. It Is Necessary To Transmit Maximum Low-Gear Torque Developed By The Engine During The Operation.
3. The Drive Shafts Must Also Be Capable Of Rotating At The Very Fast Speeds Required By The Vehicle.

2.2 Demerits Of A Conventional Drive Shaft

1. They Have Less Specific Modulus & Strength.
2. They Have Increased Weight.
3. Steel Drive Shafts Have Less Damping Capacity.
4. Its Corrosion Resistance Is Less As Compared With Composite Materials.

2.3 Merits Of Composite Drive Shaft

1. They Have High Specific Modulus And Strength.
2. They Possess Property Like Reduced Weight.
3. As The Weight Reduces, Fuel Consumption Will Be Reduced.
4. They Have Good Corrosion Resistance.
5. Greater Torque Capacity Than Steel Shaft.

III. Aluminum Alloy

Al Is A Bendable Argent Hued Versatile Metal That Is Possessing Large Amounts Of The World's Outside Layer. It Is Foolish To Collect It In Its Valid Life Systems After Actinic Responses; If Clear To Air It Anon Shapes An Oxide Band On The Evident Which Will Go About As A Cautious Safeguard From Included Oxidation. It Has A Low Body Contrasted With Included Metals Which Makes It One Of The Best Decisions For Achievement Mechanical Assembly Adjusted In On Fire Weight Applications. Utilizing Al In Its Bona Fide Life Systems Is Not Lovable As They Acknowledge Practically Bring Down Quality. In Appearance Of This Modified Al Based Combinations And Composites Acknowledge Been Produced To Upgrade These Elements While Befitting A Ton Of The Adjusted Scenery Of The Miserable Metal (Al) Exhibit In The Shaped Admixture Or Composite. Different Sorts Of Al Composites Acknowledge Been Adjusted Liberally Over The Refined Decades In Aviation And Car Businesses.

Table 3.1Properties Of Aluminum Alloy

Yield Stress	18Mpa
Density	2700kg/Mm^3
Poisson's Ratio	0.33
Young's Modulus	72Gpa
Shear Strength	95Mpa

IV. Why Carbon/Epoxy Composites??

Carbon Adhesive Blended Shows Top Compactness (Strength) Power, Top Modulus Acerbity When Compared With Added Composites. Carbon Adhesive Blended Shows Different Damping Characteristics. Carbon Adhesive Blended Shows Absolute Accessory Of Thermal-Amplification Like Compactness Backbone The Blend Increase With Temperature. Carbon Adhesive Blended Is Fatigue, Abrasive As Well As Bane Resistant.

Table 4.1- Material Property Of Composite Materials

Properties	Unit	HS Carbon And Epoxy	HM Carbon And Epoxy
E_{11}	Gpa	134	190
E_{22}	Gpa	7.0	707
G_{12}	Gpa	5.8	402
V_{12}	-	0.3	0.3
$S^t_1 = S^c_1$	Mpa	880	870
$S^t_2 = S^c_2$	Mpa	60	54
S_{12}	Mpa	87	30
Density	Kg/M^3	1600	1600

V. Design Analysis

Finite Element Analysis (FEA) Is A Computer-Based Numerical Technique For Calculating The Strength And Behavior Of Engineering Structures. It Can Be Used To Calculate Deflection, Stress, Vibration, Buckling Behavior And Many Other Phenomena. It Also Can Be Used To Analyze Either Small Or Large Scale Deflection Under Loading Or Applied Displacement. It Uses A Numerical Technique Called The Finite Element Method (FEM). In Finite Element Method, The Actual Continuum Is Represented By The Finite Elements. These Elements Are Considered To Be Joined At Specified Joints Called Nodes Or Nodal Points. As The Actual Variation Of The Field Variable (Like Displacement, Temperature And Pressure Or Velocity) Inside The Continuum Is Not Known, The Variation Of The Field Variable Inside A Finite Element Is Approximated By A Simple Function. The Approximating Functions Are Also Called As Interpolation Models And Are Defined In Terms Of Field Variable At The Nodes. When The Equilibrium Equations For The Whole Continuum Are Known, The Unknowns Will Be The Nodal Values Of The Field Variable. In This Project Finite Element Analysis Was Carried Out Using The FEA Software ANSYS. The Primary Unknowns In This Structural Analysis Are Displacements And Other Quantities, Such As Strains, Stresses, And Reaction Forces, Are Then Derived From The Nodal Displacements.

5.1 – Static Analysis

Static Analysis Deals With The Conditions Of Equilibrium Of The Bodies Acted Upon By Forces. A Static Analysis Can Be Either Linear Or Non -Linear. All Types Of Non-Linearities Are Allowed Such As Large Deformations, Plasticity, Creep, Stress Stiffening, Contact Elements Etc. This Chapter Focuses On Static Analysis. A Static Analysis Calculates The Effects Of Steady Loading Conditions On A Structure, While Ignoring Inertia And Damping Effects, Such As Those Carried By Time Varying Loads. A Static Analysis Is Used To Determine The Displacements, Stresses, Strains And Forces In Structures Or Components Caused By Loads That Do Not Induce Significant Inertia And Damping Effects. A Static Analysis Can However Include Steady Inertia Loads Such As Gravity, Spinning And Time Varying Loads. In Static Analysis Loading And Response Conditions Are Assumed, That Is The Loads And The Structure Responses Are Assumed To Vary Slowly With Respect To Time. The Kinds Of Loading That Can Be Applied In Static Analysis Includes, Externally Applied Forces, Moments And Pressures .Steady State Inertial Forces Such As Gravity And Spinning Imposed Non-Zero Displacements. A Static Analysis Result Of Structural Displacements, Stresses And Strains And Forces In Structures For Components Caused By Loads Will Give A Clear Idea About Whether The Structure Or Components Will Withstand For The Applied Maximum Forces. If The Stress Values Obtained In This Analysis Crosses The Allowable Values It Will Result In The Failure Of The Structure In The Static Condition Itself. To Avoid Such A Failure, This Analysis Is Necessary.

5.2 - Buckling Analysis

Buckling Analysis Is A Technique Used To Determine Buckling Loads (Critical Loads) At Which A Structure Becomes Unstable, And Buckled Mode Shapes (The Characteristic Shape Associated With A Structure's Buckled) For Thin Walled Shafts, The Failure Mode Under An Applied Torque Is Torsional Buckling Rather Than Material Failure. For A Realistic Driveshaft System, Improved Lateral Stability Characteristics Must Be Achieved Together With Improved Torque Carrying Capabilities. The Dominant Failure Mode, Torsional Buckling, Is Strongly Dependent On Fiber Orientation Angles And Ply Stacking Sequence.

5.3 - Modal Analysis

When An Elastic System Free From External Forces Is Disturbed From Its Equilibrium Position It Vibrates Under The Influence Of Inherent Forces And Is Said To Be In The State Of Free Vibration. It Will Vibrate At Its Natural Frequency And Its Amplitude Will Gradually Become Smaller With Time Due To Energy Being Dissipated By Motion. The Main Parameters Of Interest In Free Vibration Are Natural Frequency And The Amplitude. The Natural Frequencies And The Mode Shapes Are Important Parameters In The Design Of A Structure For Dynamic Loading Conditions. Modal Analysis Is Used To Determine The Vibration Characteristics Such As Natural Frequencies And Mode Shapes Of A Structure Or A Machine Component While It Is Being Designed. It Can Also Be A Starting Point For Another More Detailed Analysis Such As A Transient Dynamic Analysis, A Harmonic Response Analysis Or A Spectrum Analysis. Modal Analysis Is Used To Determine The Natural Frequencies And Mode Shapes Of A Structure Or A Machine Component. The Rotational Speed Is Limited By Lateral Stability Considerations. Most Designs Are Sub Critical, I.E. Rotational Speed Must Be Lower Than The First Natural Bending Frequency Of

The Shaft. The Natural Frequency Depends On The Diameter Of The Shaft, Thickness Of The Hollow Shaft, Specific Stiffness And The Length.

VI. Design Parameters:

6.1- Mass Of The Designed Composite Drive Shaft
6.2 - Torque Transmission Capacity Of Designed Composite Drive Shaft
6.3– Torsional Buckling Capacity
6.4-Fundamental Natural Frequency (F)
6.5 - Deformation
6.6 - Buckling Load

Table- 6.1 Composite Drive Shaft Design Parameter

Parameters	Symbol	Values	Units
Outer Diameter	D_o	25	Mm
Inner Diameter	D_i	20	Mm
Length	L	175	Mm
Thickness	T	5	Mm

VII. Results And Discussion

A Composite Drive Shaft With Single Piece Was Designed Using Catia & Its Analysis Was Done Using Ansys Workbench For Material Having High Power(Strength)Carbon And Epoxy And High Modulus Carbon And Epoxy Composite With The An Idea Of Minimizing Its Weight Which Is Subjected To Constraint Like Torsional Buckling Capacity, Natural Frequency And Torque Transmission.

7.1 – Results Of Weight Reduction

Parameters	**Al-Alloy**	**HS Carbon And Epoxy**	**HM Carbon And Epoxy**
D_o(Mm)	25	25	25
L (Mm)	175	175	175
T_k(Mm)	5	5	5
Layer's	1	10	10
Stacking Sequence	_	$[0/30/45/60/90]_S$	$[0/30/45/60/90]_S$
Weight (Kg)	0.0834	0.0494	0.0494

7.2- Static Analysis Results

Material	Al- Alloy	HS Carbon And Epoxy	HM Carbon And Epoxy
Stacking Sequence	-	$[0/30/45/60/90]_S$	$[0/30/45/60/90]_S$
Deformation Theoretical(M)	1.112e-5	1.547e-5	1.132e-5
Deformation Ansys(M)	1.388e-5	1.935e-5	1.446e-5

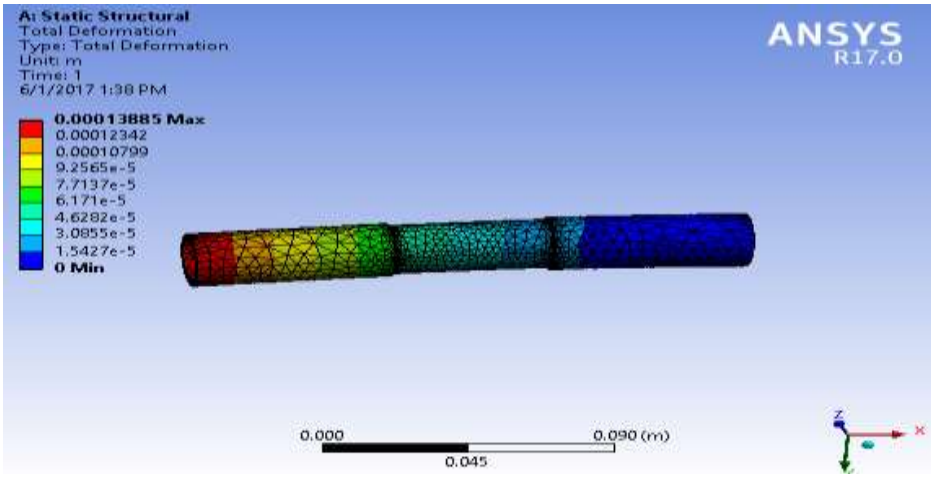

Fig 7.1 – Figure Showing Deformation Of Al-Alloy

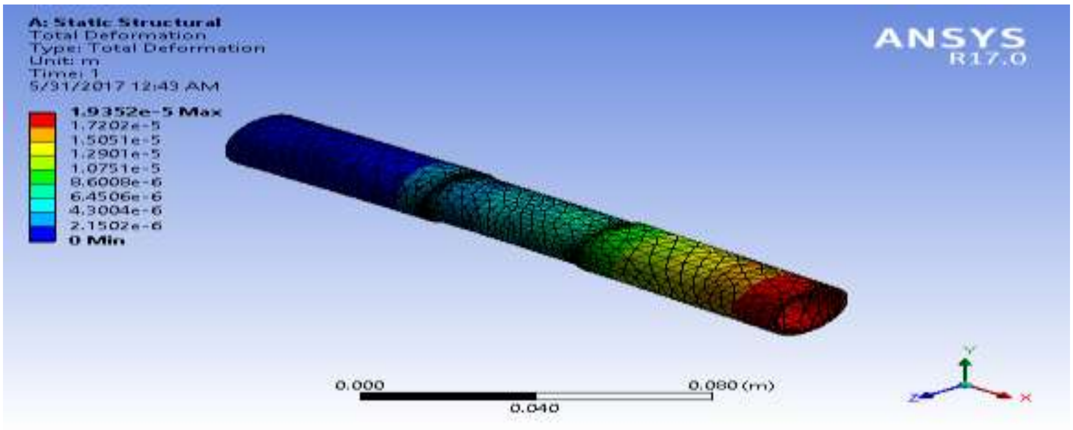

Fig 7.2 –Figure Showing Deformation Of HS Carbon/Epoxy (0/30/45/60/90)S

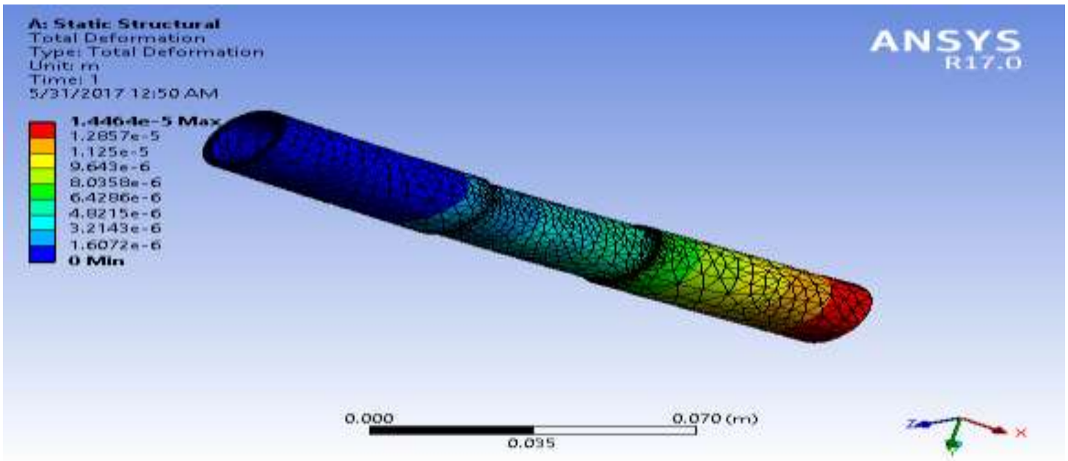

Fig 7.3 –Figure Showing Deformation Of HM Carbon/Epoxy (0/30/45/60/90)S

7.3 – Buckling Results

Material	Al- Alloy	HS Carbon And Epoxy	HM Carbon And Epoxy
Stacking Sequence	-	$[0/30/45/60/90]_S$	$[0/30/45/60/90]_S$
Buckling Theoretical(N)	64754	10419	13892
Buckling Ansys (N)	62304	9044	12059

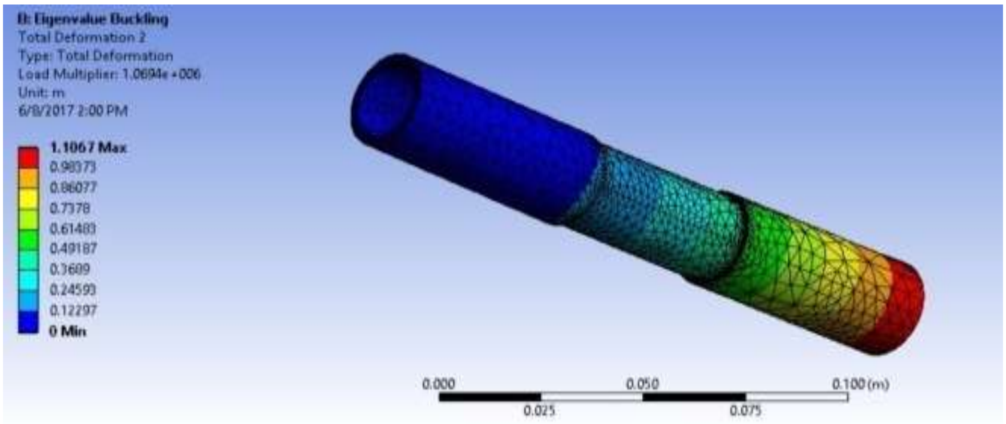

Fig 7.4 – Figure Showing Buckling Results For Al-Alloy

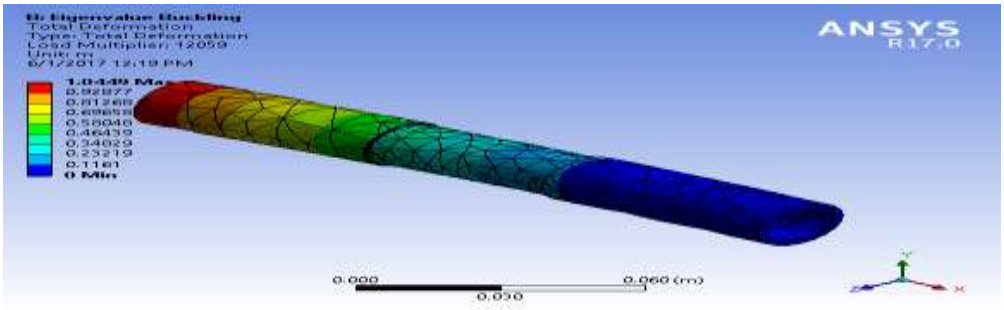

Fig 7.5 – Figure Showing Buckling Results For HS Carbon/Epoxy(0/30/45/60/90)S

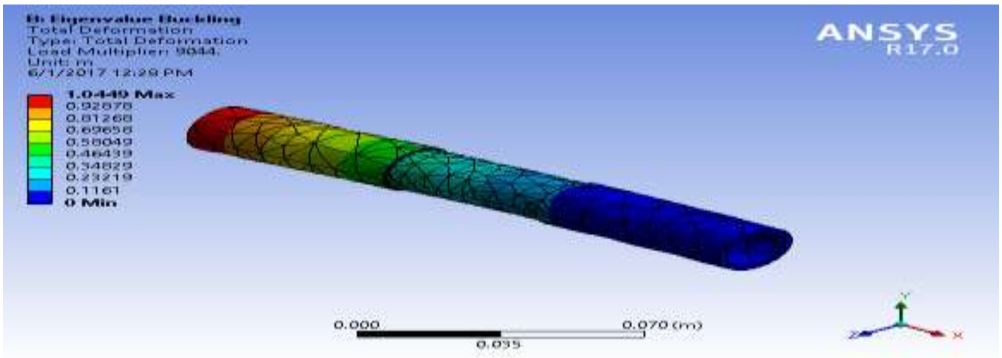

Fig 7.6 – Figure Showing Buckling Results For HM Carbon/Epoxy(0/30/45/60/90)S

7.4 – Modal Results

Material	Al -Alloy	HS Carbon And Epoxy	HM Carbon And Epoxy
Stacking Sequence	-	$[0/30/45/60/90]_S$	$[0/30/45/60/90]_S$
Natural Frequency Theoretical(Hz)	8013	16767	19354
Natural Frequency Ansys(Hz)	6945	14540	16801

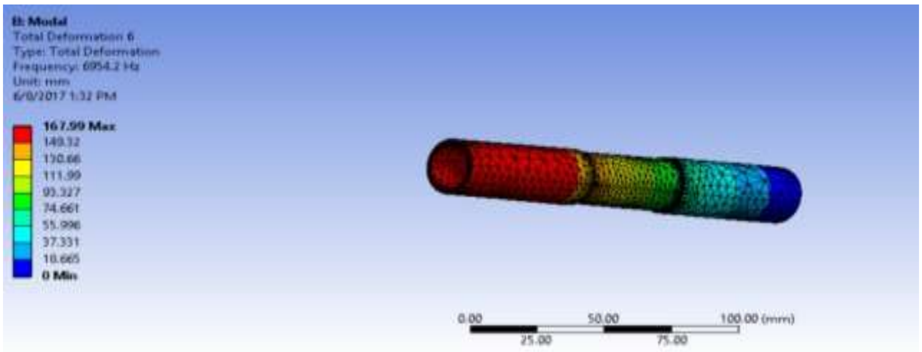

Fig 7.7-Figure Showing Modal Results For Al-Alloy

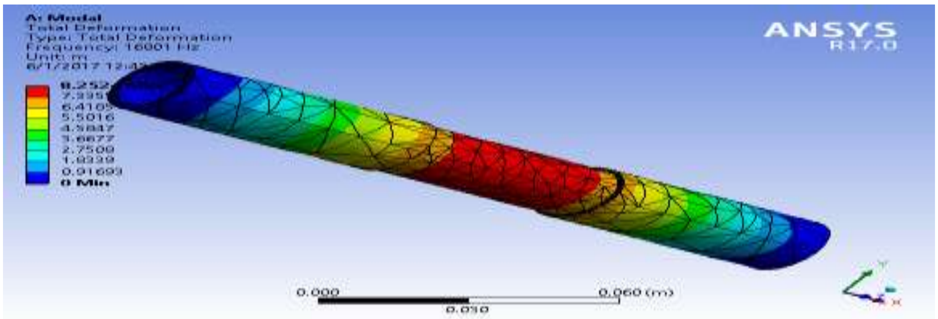

Fig 7.8 – HS Carbon/Epoxy(0/30/45/60/90)S

VIII. Conclusion

The Following Conclusions Are Drawn From The Present Work. Aluminum Alloy, High Strength Carbon/ Epoxy And High Modulus Carbon/Epoxy Composite Drive Shifts Have Been Designed To Replace The Steel Drive Shaft Of An Automobile. A Composite Drive Shaft For Wheel Drive Automobile Has Been Designed For Aluminium Alloy, High Strength Carbon/ Epoxy And High Modulus Carbon/ Epoxy Composites With The Objective Of Minimization Of Weight Of The Shaft Which Was Subjected To The Constraints Such As Torque Transmission, Torsional Bucking Capacities And Natural Bending Frequency. The Weight Was Found For Aluminium Alloy, High Strength Carbon/ Epoxy And High Modulus Carbon/ Epoxy Shafts Were Equal 0.0834, 0.0494 And 0.0494 Respectively. The Fundamental Natural Frequency Of Aluminium Alloy, High Strength Carbon/Epoxy And High Modulus Carbon/ Epoxy Shafts Were 6945,14540 And 16801 Respectively. Buckling Capacity Was Higher In Aluminium Alloy Than That Of Carbon/Epoxy.

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