Investigation of Performance Analysis for Composite Helical Compression Spring and Steel Compression Spring

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Abstract
The current work is focused on studying and analyzing spring design with the goal of replacing traditional steel material with composite material such as Kevlar, epoxy glass, and epoxy carbon. Experiments will be carried out to verify the conventional spring's static deflection and stiffness. These experiments will make use of the finite element approach, which is implemented inside ANSYS software. By using the finite element approach in ANSYS, we will determine the static deflections and stiffness of every composite spring. The stiffness of composite springs and traditional springs will be evaluated, and a recommendation will be made for the best material overall. The design of the spring will be evaluated with regard to the weight of the bike, as well as the weight of a single person and of two people riding together. CATIA V5 and ANSYS are the programs that are used to do the modeling and analysis, respectively. Existing springs and those made of brand-new material will both be used as points of comparison in this research. In FEA, static analysis is the process that determines the stresses and deflections caused by helical compression.

Key Words: *Composite Material, ANSYS, FEA, Helical Coil Steel Spring, CATIA V5.*
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I. INTRODUCTION

The primary purpose of the helical compression spring is to act as a shock absorber, dampen vibrations, and make the driving experience more comfortable for the operator. In the manufacturing business, springs are used primarily as members for the purpose of absorbing shock energy and restoring the original position of a component after it has been displaced for the purpose of commencing a particular function. Compression springs are helical coil springs that are designed to withstand an axially applied compressive force. Compression springs may have a variety of different shapes, including cylindrical, conical, tapered, concave, or convex. The research that is being done in the automotive industry right now is mostly focused on the utilization of unconventional materials in lieu of traditional materials. Composite materials are an alternative to traditional materials that are employed in many of the components of cars. A composite material is one that is made up of a blend of two or more different types of materials. When compared to traditional materials, components made using composite materials have a lower overall weight while retaining the same level of mechanical strength as those made with traditional materials. This results in the solution to the challenge of weight reduction that the automotive manufacturing industry will confront in a few decades. Typically made from round wire, coil compression springs are twisted in the shape of a helix. Cyclic loading is applied to the spring on a regular basis for the purpose of the application in question, and the greatest frequency of use that is anticipated is between 5 and 50 cycles per minute. When considering the anticipated service life of 10–15 years, the spring should be able to endure cyclic compression loads for a few million times at the very least. The springs need to have a design that ensures their dependability. The springs need to be constructed such that they can sustain the cyclic loading that occurs when the machine is in operation. As a result, it has been suggested that the design and fatigue study of a compression spring be carried out as part of this research effort in order to achieve superior performance in terms of long service life.

II. LITERATURE SURVEY

For the study point of view, we have selected some research articles which are mentioned as follows:

I Balaguru, et al. (2016) [1] "suggested the improvement of fuel efficiency of vehicles by reducing the weight of the vehicle. They examined design and production methods for FRP composite helical springs anddrew the following conclusions: Carbon fiber springs are lighter than glass and glass/carbon fiber springs. Carbon fiber coil springs are stiffer than conventional varieties. Glass fiber/carbon fiber springs perform poorly compared to other varieties. Braided + Unidirectional + Rubber core offers greater mechanical qualities than Unidirectional, Unidirectional+ Rubber core, and Outer braid + Unidirectional. Composite helical springs may be substituted in lightweight automobiles with a little size compromise. In ordinary automobiles, combining composite and conventional springs may overcome the poor rigidity of compositesand optimize spring weight".

D. Abdul Budan et al. (2010) [2] "investigated the feasibility of composite coil springs for Automotive Applications. They showed that composite coil springs can replace metal ones. Glass fiber, carbon fiber, and a mixture were used to make springs. The study aims to minimize spring weight. The carbon fiber spring rate is 34% higher than the glass fiber spring and 45% higher than the glass fiber/carbon fiber spring. Carbon fiber springs are 18% lighter than glass fiber, 15% lighter than glass fiber/carbon fiber, and 80% lighter than steel. Composite springs are lighter and stiffer than steel springs. (A steel spring of the same size springs 14 N/mm and weighs 1.078 kg.) These springs' experimental findings led to the following conclusions. Carbon fiber springs are lighter than glass and glass/carbon fiber springs. Carbon fiber coil springs are stiffer than conventional varieties. Glass fiber/carbon fiber roving springs perform poorly compared to other varieties".

Bok-Lok Choi a., et al. (2015) [3] "investigated numerical and experimental methods for determining the ply angles and wire diameters of carbon fiber/epoxy composite coil springs to attain a spring rate equal to that of an equivalent steel component. The inverse connection between twist angle and shear modulus predicted the composite's equivalent shear modulus. The shear modulus for a composite with a 450 ply angle was 16.8% of that of steel, and the calculated shear modulus was in excellent accord with experimental data. With an optimal ply angle of 450, a composite coil spring's wire diameter will be 17.17 mm. FEA and experimental findings for a composite coil spring with a 450 ply angle agreed well. Applying the proposed analytical and experimental approaches to a composite coil spring resulted in a 55% weight reduction".

M. Sudheer, et.al. (2015) [8] "studied the Analytical and Numerical Validation of Epoxy/Glass Structural Composites for Elastic Models. Elastic characteristics like Young's modulus (E1 and E2) and Poisson's ratio (v12 and v21) are assessed for n various volume fractions along the material's primary directions (FEM). The solver was ANSYS. These computer conclusions are contrasted with analytical results from the Rule of a mixture, Halpin-Tsai, Nielsen, and Chamis elastic models. This work compared computational and analytical data to find the optimal elastic characteristics. The Epoxy/Glass composite is more effective when loaded along the fiber direction".

Sujit S Patil, et. al. (2016) [9] "analyzed that the composite helical springs can be effectively used in automobiles without affecting the performance of the suspension system of the vehicles. They're 50%-70% lighter than steel springs. E-glass/Epoxy spring costs 20% more than steel but is 50% lighter with the same performance. Carbon/Epoxy springs are 5 times more expensive than steel but much lighter. Composite spring stiffness is similar to steel. Suspension systems can successfully employ composite springs".

Sid Ali Kaouaa, et. al. (2011) [4] "presented a 3D geometric modeling of a twin helical spring and its finite element analysis to study the spring mechanical behavior under tensile axial loading. Using computer-aided design (CAD) tools, a finite element model is produced to create the graphic design of the spiraling form. As a result, the complicated "wired shape" of the spring is discretized using 3D 18-DOF pentameric components, enabling the measurement of the mechanical reaction of the twin spiraled helical spring under an axial load. With sinusoidal behavior, the analysis shows a strong correspondence between the evolution of the theoretical and numerical tensile and compression normal stresses. The internal radial zone at section 1800 has the highest value of the total equivalent stress ISO values, which grow radially from 00 to 1800. On the other side, the filament cross-center section's is where the least amount of tension is present".

Wang, F. (2001) [10] "discussed the active suspension control of vehicle models. It contains two main parts. First, mechanical network analysis showed the need for active suspension. He used conventional network theory to prove that half- and full-car models need active suspension in certain conditions. When a soft passive suspension is used for road disturbances, a firm passive suspension is used for load disturbances. In the second phase of the study, he parametrized all stabilizing controllers for a specific plant while fixing a closed-loop transfer function. He defined left and right normal rank factorizations of a rational matrix to aid parametrization. Under some situations, the residual transmission pathways' performance may approach the original set. The findings are then used to create controller architectures for quarter-, half-, and full-car models. He outlined the basic assumptions needed to decompose a half-car into two quarter-cars. He uses symmetry to partition a full-car model into bounce/pitch and roll/warp half-car models. Warp mode reduces chassis twisting forces. For complicated models, numerical controller structure calculations are described and applied to double-wishbone models. The trailing-arm model illustrates his work's primary concepts. He explains anti-squat and anti-dive trailing-arm design. Network analysis suggests an active suspension to meet performance objectives. This model's active suspension is designed using disturbance response decoupling. AutoSim was utilized to simulate car models together with theoretical studies during this endeavor. This research's analysis and synthesis approaches may be used to complicated models”.

Skewis, W. H. (2017) [7] “experimentally examined Very high cycle fatigue (VHCF) properties of a newly developed clean spring steel under rotating bending and axial loading. This steel has the duplex S–N property solely for surface-induced failure under rotational bending, but only the single S–N propertyunder axial stress. This steel's VHCF failure mechanism is a minor grinding defect-induced failure. The surface morphology of the interior inhomogeneous microstructure with distinct plastic deformation is much rougher than that of the ambient matrix, which means stress concentration from strain inconsistencybetween the microstructural inhomogeneity as the soft phase and the ambient matrix as the hard phase causes interior crack initiation. The threshold stress intensity factor for surface small defect-induced fracture propagation of this steel is 2.04 MPam1/2, which suggests the short crack effect plays a crucial role in inducing surface small defect-induced failure in the VHCF regime. Under a certain flaw density, surface and interior failure probability are similar. If the inner defect size is less than or equal to the surfacedefect size, surface defect-induced failure will dominate in VHCF, particularly under rotational bending”.

Michalczyk, K. (2013) [5] “presented the analysis of elastomeric coating’s influence on dynamic resonant stressed values in spring. The appropriate equations determining the effectiveness of dynamic stress reduction in resonant conditions as a function of coating parameters were derived. It was proved that rubber coating will not perform in a satisfactory manner due to its low modulus of elasticity in shear. It wasalso demonstrated that about-resonance areas of increased stresses are wider and wider along with the successive resonances and achieve significant values even at large distances from the resonance frequencies”

Pyttel, B., et.al.(2014) [6] “conducted Long-term fatigue tests on shot-peened helical compression springs by means of a special spring fatigue testing machine at 40 Hz. Test springs were made of three different spring materials – oil-hardened and tempered SiCr- and SiCrV-alloyed valve spring steel and stainless steel. With a special test strategy in a test run, up to 500 springs with a wire diameter of d = 3.0 mm or 900 springs with d = 1.6 mm were tested simultaneously at different stress levels. Based on fatigue investigations of springs with d = 3.0 mm up to a number of cycles N = 109 an analysis was done after the test was continued to N = 1.5 × 109 and their results were compared. The influence of different shot peening conditions was investigated in springs with d = 1.6 mm. Fractured test springs were examined under an optical microscope, scanning electron microscope (SEM), and by means of metallographic microsections in order to analyze the fracture behavior and the failure mechanisms. The paper includes a comparison of the results of the different spring sizes, materials, number of cycles, and shot peening conditions and outlines further investigations in the VHCF region”.

The current study demonstrates how composite materials may successfully replace steel springs in helical compression springs used in vehicles. These springs are used in a compression configuration. In this experiment, the performance characteristics of composite helical springs are contrasted with those of a steel spring taken at random from a two-wheeler vehicle.

III. RESEARCH OBJECTIVE

In the past, ordinary steel was used in suspension systems as a helical coil spring to increase performance. Although conventional steel is more affordable and durable than alternative materials, its weight poses a serious obstacle to its application. The research focuses on the use of composite materials to reduce the weight of springs. Therefore, we chose a composite material that can provide an average performance while using little weight. Additionally, it has improved stiffness, elastic strength, and fatigue characteristics.

IV. METHODOLOGY

The suggested technique is divided into three distinct stages.
Phase 1: Analytical calculations are compared to a traditional finite element study of a steel spring.
Phase 2: Experimental investigation to determine static deflection for steel material using a standard spring.
Phase 3: Composite material Finite Element Analysis (Glass Epoxy, carbon epoxy, and Kevlar).

V. ANALYSIS OF SPRING

Utilizing ANSYS 16.0, a static analysis of the spiral spring design is done to determine the maximum safe stress for the appropriate payload. Hero Passion Motorcycle helical spring is analyzed as a conventional spring utilizing the following three loading scenarios:

Table 1: Loading Conditions for Study

Case No	Load	Loading Conditions
1.	735 N	Wt. of Motorcycle
2.	1176 N	Wt. of bike + 1Person wt
3.	1618 N	Wt. of bike + 2 Person wt.

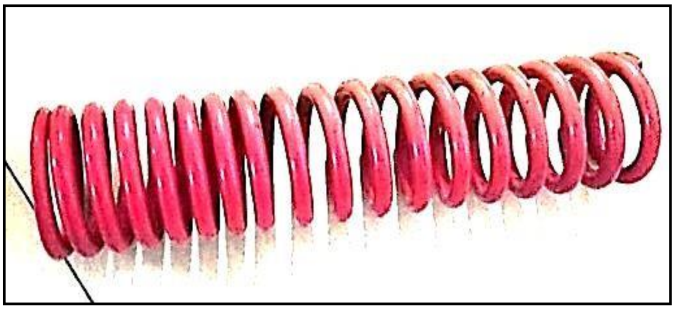

Figure 1. Hero Passion Motor Cycle Helical Steel Spring

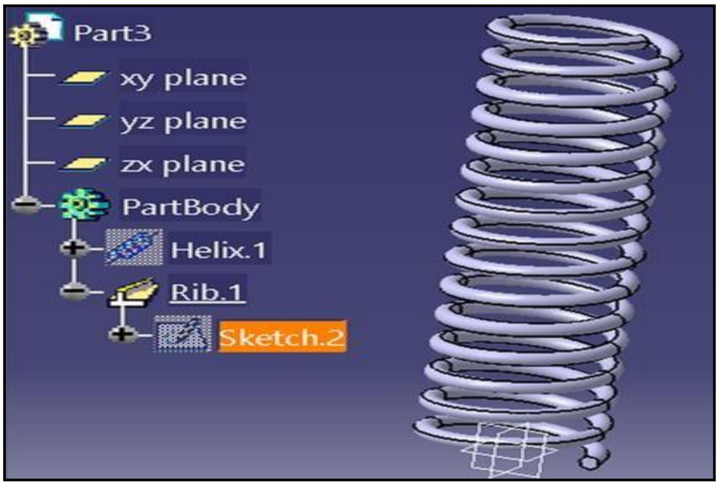

Figure 2 Model of conventional steel spring using CATIA V5

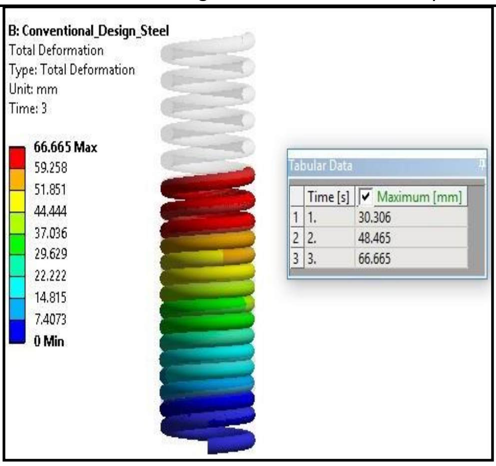

Figure.3 Static Deflection in Steel Spring

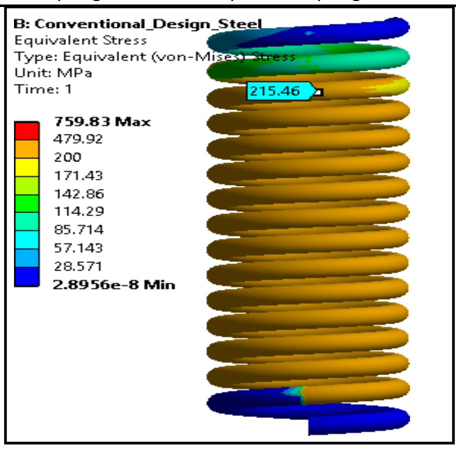

Figure.4 Stress Plot Load Case1Related to Steel Spring

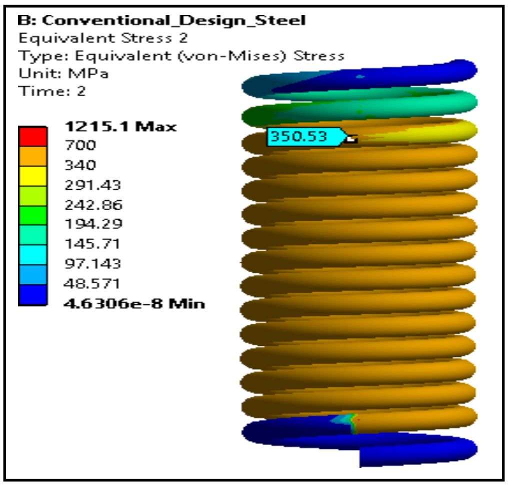

Figure.5 Stress Plot Load Case 2 Related to Steel Spring

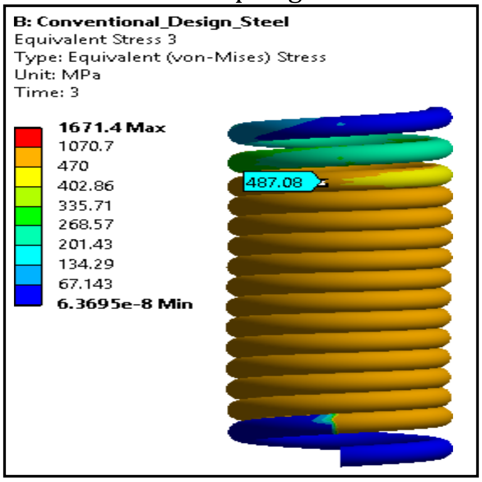

Figure.6 Stress Plot Load Case 3 Related to Steel Spring

Three load cases are defined to simulate three different cases mentioned in the objective. Figure. 4, Figure.5, and Figure. 6 show the conventional steel spring in three loading conditions.

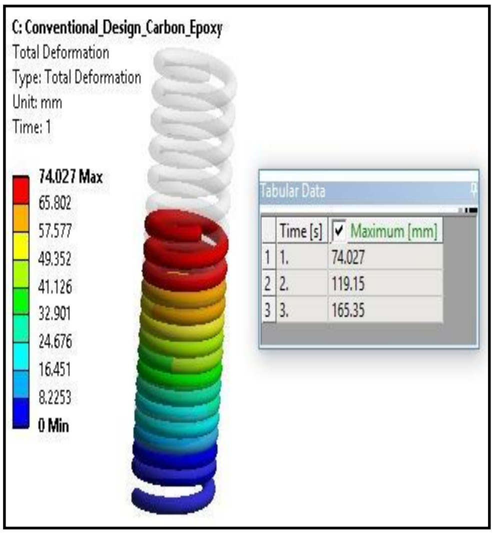

Figure.7 Static Deflection in Glass Epoxy material

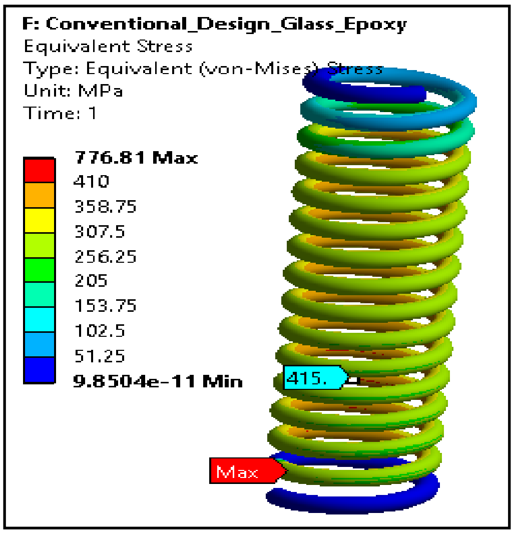

Figure.8 Stress Plot Load Case1 Related to Glass Epoxy material

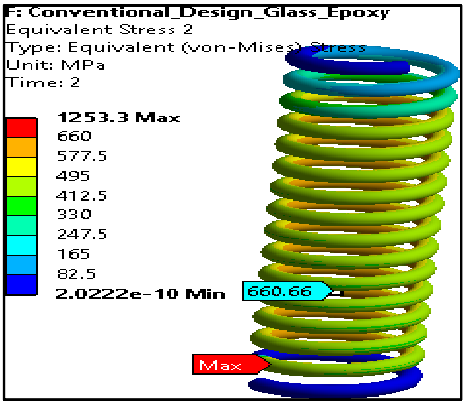

Figure 9. Stress Plot Load Case 2 Related to Glass Epoxy material

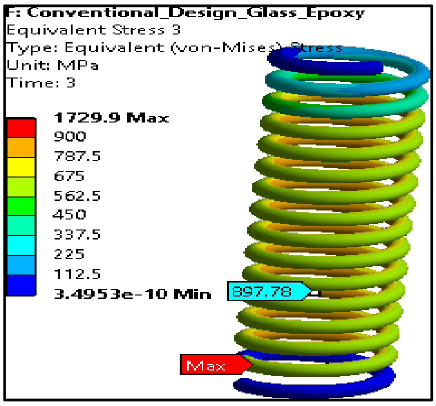

Figure10. Stress Plot Load Case 3 Related to Glass Epoxy material

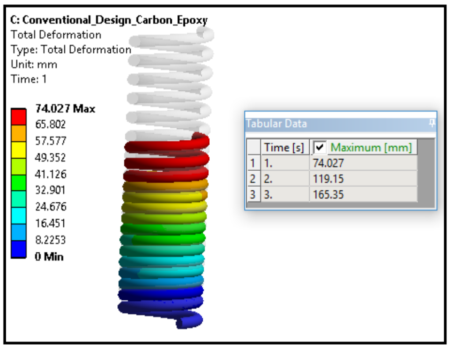

Figure 11. Static Deflection in Carbon Epoxy Material

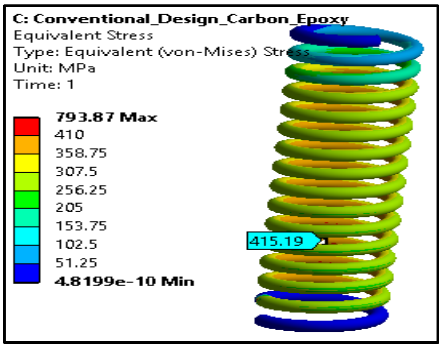

Figure 12. Stress Plot Load Case Related to Carbon Epoxy Material

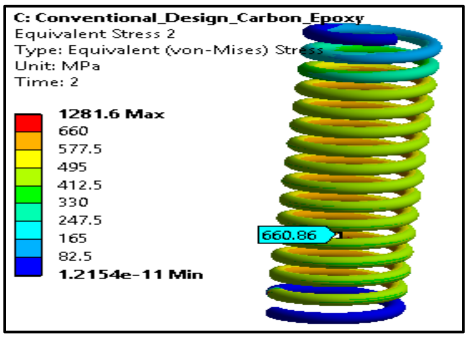

Figure 13. Stress Plot Load Case 2 Related to Carbon Epoxy Material

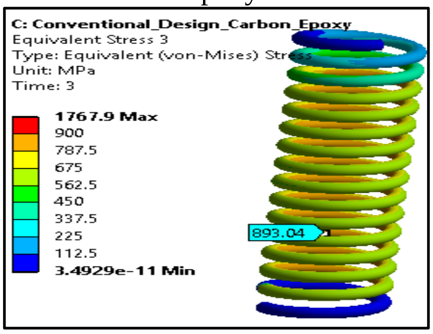

Figure 14. Stress Plot Load Case 3 Related to Carbon Epoxy Material

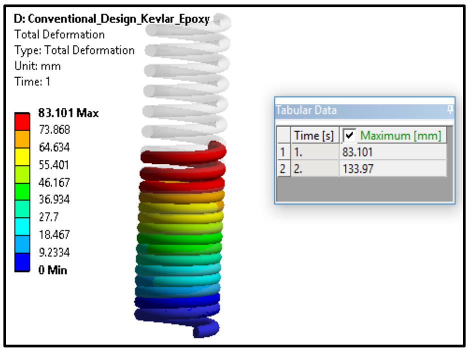

Figure15. Static Deflection in Kevlar Material

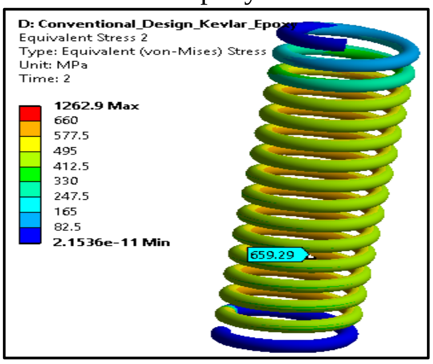

Figure 16. Stress Plot Load Case 1 Related to Kevlar Material

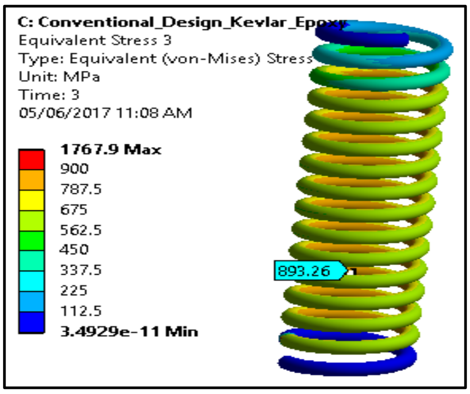

Figure 17. Stress Plot Load Case 2 Related to Kevlar Material

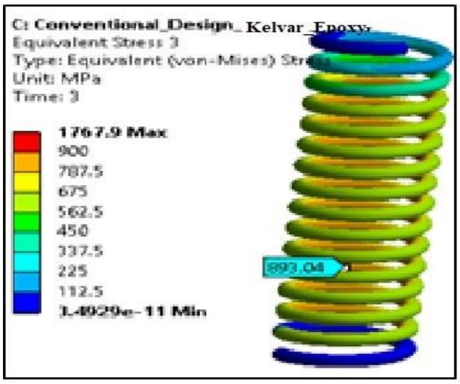

Figure 18. Stress Plot Load Case 3 Related to Kevlar Material

VI.RESULTS AND DISCUSSION

The results of the investigation are summarized as follows:

Table 2. Static Deflection in Steel Spring

Case No.	Load	Weight Combination	Static Deflection (mm) FEA Value	Analytical Value	Experimental Value
1.	735 N	Wt. of bike	29.40	30.00	29.60
2.	1176 N	Wt. of bike + 1 person	47.70	49.00	49.20
3.	1618 N	Wt. of bike + 2 person	68.11	67.00	67.32

Table 3. Bending Stress in Steel Spring

Case No.	Load	Bending Stress (MPa) FEA Value	Analytical Value	% Variation
1.	735 N	214	219	-2%
2.	1176 N	349	351	0%
3.	1618 N	486	483	1%

Table 4. Comparison of Static Deflection in Composits

Case No.	Load	Static Deflection (mm) Steel Material	Glass Epoxy Material	Carbon Epoxy Material	Kevlar Epoxy Material
1.	735 N	31.31	81.385	75.027	84.101
2.	1176 N	49.47	130.49	120.15	134.87
3.	1618 N	67.67	180.3	166.35	185.869
Weight (kg.)		0.946	0	0.192	0.158
% Respect to steel			66%	79%	81%

Table 5. Comparison of Von Mises Stress in Composites

Case No.	Load	Von Mises Stress(MPa)			
		Steel Material	Glass Epoxy Material	Carbon Epoxy Material	Kevlar Epoxy Material
1.	735 N	414.20	416.00	416.10	416.41
2.	1176 N	663.40	661.30	661.70	660.19
3.	1618 N	909.50	898.70	894.10	894.16
Tensile Strength(MPa)		450	3350	3340	3350

Table 6. Comparison of Factors of Safety in Composits

Case No.	Load	Factor of Safety			
		Steel	Glass Epoxy	Carbon Epoxy	Kevlar Epoxy
1.	735 N	1.11	8.31	8.29	8.30
2.	1176 N	0.70	5.22	5.21	5.23
3.	1618 N	0.51	3.84	3.85	3.86
Tensile Strength(MPa)		450	3350	3340	3350

From Table No. 2 we can observe that there is less difference in static deflection values of FEA, Analytical, and Experimental results. The static deflection is increasing with an increase in load. From Table No. 3 we can observe that there is very less difference in bending stress values which are getting by FEA, Analytical, and Experimental results. The bending stress is increasing as an increase in load with respective time in conventional steel spring. From Tables No. 4, 5, and 6 we can conclude that compared to utilizing standard steel, adopting composite material results in a material reduction of between 70 and 80 percent. It has been discovered that composite materials have a strength that is greater than that of steel. When compared to other composite materials, Kevlar is regarded as superior since it has the smallest amount of bulk while maintaining virtually the same level of strength. The tensile strength-to-weight ratio of Kevlar is greater.

V.CONCLUSION

When compared to utilizing standard steel, adopting composite material results in a material reduction of between 70 and 80 percent. It has been discovered that composite materials have a strength that is greater than that of steel. When compared to other composite materials, Kevlar is regarded as superior since it has the smallest amount of bulk while maintaining virtually the same level of strength. A very strong connection was found between the static deflection of a steel spring and the results of an analytical computation. (2-3 percent variation) The static deflection of a steel spring and the experimental deflection have been shown to have a very strong correlation (with a difference of just two to three percent). The tensile strength-to-weight ratio of Kevlar is greater.

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