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# STRESS ANALYSIS OF COMPOSITE HELICAL SPRING (Cr-Va + Low carbon steel & Cr-Va + Stainless Steel)

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**Abstract**

Helical spring is a mechanical device which is typically used to store energy and subsequently release it, to absorb shock, or to maintain a force between contracting surface. The present work is carried out on modeling, analysis of suspension spring is to replace the existing steel helical spring used in popular two wheeler vehicle. Aim of this paper is to analyze feasibility of adopting composite material for design of helical coil spring. Combination of springs with steel and composite material i.e. mixing of carbon steel with graphite and graphite is to be used in place of conventional spring steel. The stress and deflections of the helical spring is to be reduced by using the new material. The comparative study is carried out between existing spring and new material spring. Metal matrix composite (MMC) material is used instead of fibers with combination of conventional steels. The intension behind the use of MMC is to improve overall stiffness and life of the system. The cause of implementing combination of steel and composite material is the low stiffness of single composite spring, which limits its application to light vehicles. Fuel efficiency of automobiles can be maximized by lowering the weight of the vehicle. The spring of the suspension system plays an important role for a smooth and jerk free ride. So it is required to design the springs very precisely. The use of conventional steel as spring increases the weight and manufacturing process energy required is more so manufacturers are willing to use composite materials light in weight and also have corrosion resistance, it can also withstand high temperature. Manufacturing composite material is quite costlier than the steel spring. The use of composite material is beneficial if manufacturing process is standardized it can increase the efficiency of the vehicle adherence overcome the material cost.

**Key Words:** Helical springs, coil springs, metal matrix composite, ANSYS Software.

## 1 Introduction

In order to conserve natural resources and economize energy, weight reduction has been the main focus for automobile manufacturers in the modern world. Weight reduction can be achieved primarily by introducing better materials, optimization and novel manufacturing techniques. The helical spring used in vehicle suspensions is one of the target items for weight reduction in as it accounts for 10 to 20% of the unsprung weight. This results in a vehicle with more fuel efficiency and improved riding qualities.

Helical spring is a simple form of spring, commonly used for suspension in automobiles. It is also one of the oldest forms of shock absorber; dating back to the medieval times. The merit of a helical spring over a leaf spring is that the end of the helical spring may be guided along a definite path.

The introduction of composite materials has made it possible to reduce weight of helical spring without any reduction on load carrying capacity and strength. Since, the composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel, multi-helical steel springs are being replaced by mono-helical composite springs. The composite material offers opportunities for substantial weight saving but not always be cost-effective over their steel counterparts.

A helical spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a helical spring ensures a more compliant suspension system. According to the studies made, a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a helical spring. Fortunately, composites have these characteristics. Fatigue failure is the predominant mode of in-service failure of many automobile components.

This is due to the fact that the automobile components are subjected to variety of fatigue loads like shocks caused due to road irregularities traced by the road wheels, the sudden loads due to the wheel traveling over the bumps etc. The helical springs are more affected due to fatigue loads, as they are part of the unstrung mass of the automobile.

The fatigue behavior of Glass Fiber Reinforced Plastic (GFRP) epoxy composite materials has been studied in the past. Theoretical equation for predicting fatigue life is formulated using fatigue modulus and its degrading rate. This relation is simplified by strain failure criterion for practical application. A prediction method for the fatigue strength of composite structures at an arbitrary combination of frequency, stress ratio and temperature has been presented. These studies are limited to mono-helical springs only. In the present work, a seven-helical steel spring used in passenger cars is replaced with a composite multi helical spring made of glass/epoxy composites. The dimensions and the number of leaves for both steel helical spring and composite helical springs are considered to be the same.

## 2 Literature Review

Investigation of composite helical spring in the early 60's failed to yield the production facility because of inconsistent fatigue performance and absence of strong need for mass reduction. Researches in the area of automobile components have been receiving considerable attention now. Particularly the automobile manufacturers and parts makers have been attempting to reduce the weight of the vehicles in recent years. Emphasis of vehicles weight reduction in 1978 justified taking a new look at composite springs. Studies are made to demonstrate viability and potential of

FRP in automotive structural application. The development of a liteflex suspension helical spring is first achieved. Recent developments have been achieved in the field of materials improvement and quality assured for composite helical springs based on microstructure mechanism. All these literatures report that the cost of composite helical spring is higher than that of steel helical spring. Hence an attempt has been made to fabricate the composite helical spring with the same cost as that of steel helical spring.

**Mahmood M Shokrieh et al [1],** A helical steel spring used in the rear suspension system of light vehicles is analyzed using ANSYS V5.4 software. Using the results of the steel helical spring, a composite one made from fiberglass with epoxy resin is designed and optimized using ANSYS. The objective was to obtain a spring with minimum weight that is capable of carrying given static external forces without failure. The design constraints were stresses (Tsai–Wu failure criterion) and displacements. Compared to the steel spring, the optimized composite spring has stresses that are much lower, the natural frequency is higher and the spring weight without eye units is nearly 80% lower.

**Hou et al [2]**, This paper presents the design evolution process of a composite helical spring for freight rail applications. Three designs of eye-end attachment for composite helical springs are described. The material used is glass fibre reinforced polyester. Static testing and finite element analysis have been carried out to obtain the characteristics of the spring. FEA results confirmed that there is a high interlaminar shear stress concentration. The second design feature is an additional transverse bandage around the region prone to delamination. Delamination was contained but not completely prevented. The third design overcomes the problem by ending the fibres at the end of the eye section.

**Brouwer et al [3],** The support stiffness of a parallel helical-spring flexure should ideally be high, but deteriorates with increasing displacement. This significant characteristic needs to be quantified precisely, because it limits the use of parallel helical-spring flexures in precision mechanisms. Several approximation equations were presented for determining the drive force precisely. Even at relatively large deflections the derived formulae are in good agreement with the finite element results.

**Osipenko et al [4]**, The weak joint bending (unbonded contact without friction) of the stack of slim non-uniform curved beams (leaves) with rectangular cross-sections is considered. Each helical spring has one end clamped and the other free. The basic problem is to find the shapes of the leaves under bending. This problem is reduced to the problem of finding the densities of the forces of interaction between the leaves. The uniqueness of the solution of the problem is proved. The analytical solution is constructed in the special case of two uniform straight leaves.

**Çiçek Özes et al [5]**, The aim of this study is to examine the effects of various loading conditions on the stress of a pin-loaded woven-glass fiber reinforced epoxy laminate conveying chain component. A numerical and experimental study was carried out to determine the stress distribution of composite conveying chain components used to convey loads. For the experimental study, an apparatus was developed to simulate chain components in real motion. The commercial finite element package ANSYS was used to perform the numerical analysis using a three dimensional eight-noded layered structural solid elements. Experimental and numerical studies were compared and discussed for two conditions and five different tensile forces. A good agreement between experimental results and numerical predictions is obtained.

**David Rouison et al [6]**, In this work hemp/kenaf fiber-unsaturated polyester composites were manufactured using a resin transfer molding (RTM) process. The fiber mats, with a moisture content of 4.3% at 50% relative humidity, were dried in the mold under vacuum to reach a moisture content around 1–2%. RTM composites with various fiber contents, up to 20.6% by volume, were manufactured. The performance of these samples was evaluated by measuring tensile strength and flexural strength.

The function of spring in suspension system is to distort when loaded and to recover it original shape when the load is removed and to absorb and control energy due to shocks or vibrations. Helical coil spring is normally used for the light vehicle suspension system. The performance of the suspension system fully depends upon the spring stiffness. The suspension system of an automobile is a very crucial segment of automobile vehicle. Till date, the leaf springs and helical compression springs are widely used in automobile suspension systems by most of the manufacturers. It has been studied that a suspension system plays a very important role in smooth and jerk free ride. So it is very important to design springs with high precision. The use of conventional steel as spring material increases the overall weight of the automobile suspension system and hence, the weight of entire assembly or vehicle. Previously the automobile industries were using conventional steel as a helical coil spring in suspension system to improve the performance. Conventional steel is less costly and stronger material than other but the major problem in use of this material is weight. If someone is going to increase the stiffness of the suspension system then he has to improve the design constraints like coil diameter of spring, numbers of coils, length etc. So it affects the weight of suspension system to rise. Indirectly it affects the overall performance. Therefore, we have selected composite material which can give average performance with low weight consumption. Also it has other better properties like stiffness, elastic strength, and fatigue.

This work demonstrates the study of use of helical springs in suspension systems. Helical springs which are widely used for suspension systems are generally manufactured with high carbon steel spring like EN 47. This conventionally used material has all the properties which are suitable for springs of suspension system and it also possess some properties which are the prime requirements for suspension systems. The steel spring possess all such properties. Even then, there are some major drawbacks of this material which may be stated as high weight, resistance to corrosion, conductor of electricity, etc. Hence due to this reason, the idea of design of a new composite material satisfying the above drawbacks arose.

- To reduce the weight of the suspension system so as to meet the solution to the problem mentioned earlier and to obtain higher stiffness.
- To obtain additional advantages like corrosion resistance, non conductance to heat and electricity.
- The highest potential of reducing weight of suspension system lies in the reduction of weight of suspension spring.

## 3 Material Selection

Materials constitute nearly 60%-70% of the vehicle cost and contribute to the quality and performance of the vehicle. Even a small amount in weight reduction of the vehicle, at any part could have a significant economic impact. Composite materials have proven as suitable substitutes for steel in connection with weight reduction of the vehicle. Hence, the composite materials have been selected for helical spring design.

Chromium is a ceramic compound that exists in several different chemical compositions: $Cr_3C_2$, $Cr_7C_3$, and $Cr_{23}C_6$. At standard conditions it exists as a gray solid. It is extremely hard and corrosion resistant. It is also a refractory compound, which means that it retains its strength at high temperatures as well. These properties make useful as an additive to metal alloys. When chromium carbide crystals are integrated into the surface of a metal it improves the wear resistance and corrosion resistance of the metal, and maintains these properties at elevated temperatures. The hardest and most commonly used composition for this purpose is $Cr_3C_2$.

## 4 Design Selection

The helical spring behaves like a simply supported beam and the flexural analysis is done considering it as a simply supported beam as in Fig 1. The simply supported beam is subjected to both bending stress and transverse shear stress. Flexural rigidity is an important parameter in the helical spring design and test out to increase from two ends to the center.

**Fig 1** 3D model of helical spring

## 5 Three Dimensional Finite Element Analysis

The composite helical spring is analyzed for static strength and deflection using 3D finite element analysis. The general purpose finite element analysis software ANSYS v14.5 Workbench is used for this study. Using the advantage of symmetry in geometry and loading, only one-half of the helical spring is modeled and analyzed. The three dimensional structure of the helical spring is divided into a number eight-nodded 3D brick elements. This is done by setting the appropriate attributes in the meshing tool in ANSYS software. In order to get accurate results, more number of elements are to be created. The variation of bending stress and displacement values are to be predicted.

### 5.1 Composites in ANSYS

Composite materials have been used in structures for a long time. In recent times composite parts have been used extensively in aircraft structures, automobiles, sporting goods, and many consumer products.
Composite materials are those containing more than one bonded material, each with different structural properties.
ANSYS allows us to model composite materials with specialized elements called layered elements. Once we build our model using these elements, we can do any structural analysis (including nonlinearities such as large deflection and stress stiffening).

### 5.2 Element Type used for Analysis

SOLID45 is used for the 3-D modeling of solid structures (refer Fig 2). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions.

The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

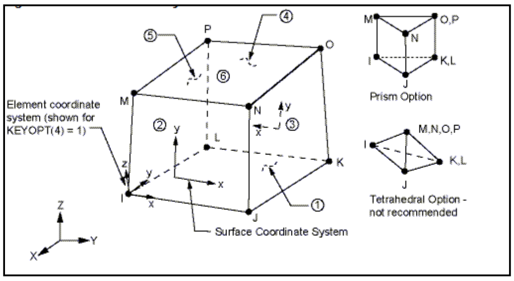


**Fig 2** SOLID45 Geometry

### 5.3 TARGE170 Element Description

TARGE170 is used to represent various 3-D "target" surfaces for its associated contact elements (CONTA173, CONTA174, CONTA175, CONTA176 & CONTA177). Geometry of the element is as given in Fig 3. The contact elements themselves overlay the solid, shell, or line elements describing the boundary of a deformable body and are potentially in contact with the target surface, defined by TARGE170. This target surface is discretized by a set of target segment elements (TARGE170) and is paired with its associated contact surface via a shared real constant set.

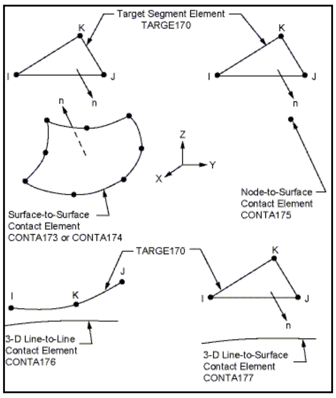


**Fig 3** TARGE170 Geometry

## 6 Results and Discussion

### 6.1 Conventional Steel:

The following figures show the results from the ANSYS solver for the conventional steel helical spring under load. Fig 4 shows the total deformation of the spring. Fig 5, Fig 7 and Fig 9 shows the elastic strain intensity, normal elastic strain, and shear elastic strain respectively. Fig 6 shows the equivalent stress (von mises) in the spring. Fig 8, Fig 10, and Fig 11 show the normal stress, shear stress, and stress intensity of the loaded spring.

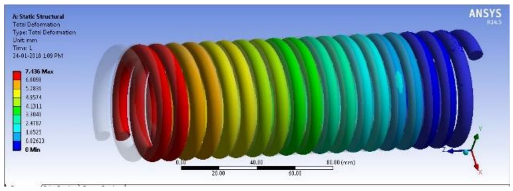

**Fig 4** Total Deformation

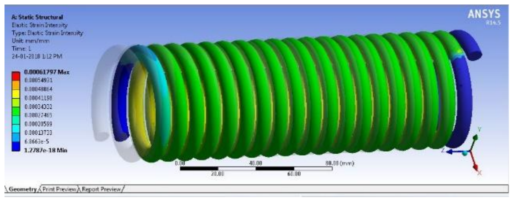

**Fig 5** Elastic Strain Intensity

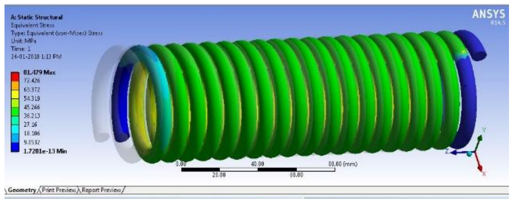

**Fig 6** Equivalent Stress (von Mises)

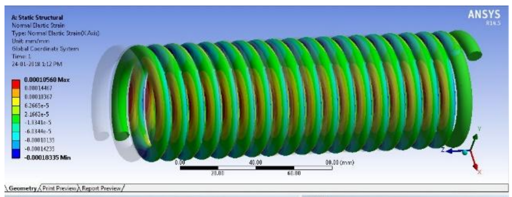

**Fig 7** Normal Elastic Strain

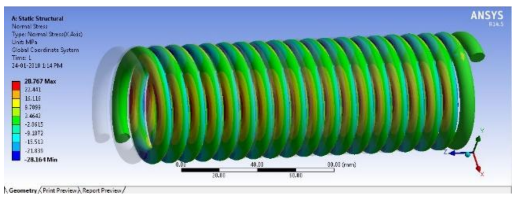

**Fig 8** Normal Stress

5

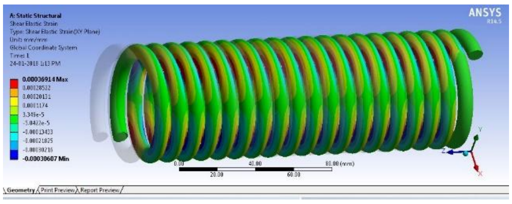


**Fig 9** Shear Elastic Strain

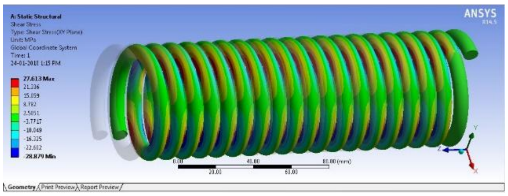


**Fig 10** Shear Stress

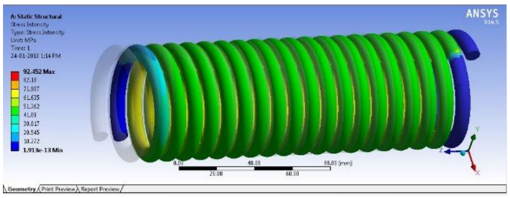


**Fig 11** Stress Intensity

### 6.2 Chromium-Vanadium + Low Carbon Steel:

The following figures show the results from the ANSYS solver for the composite helical spring, which is Cr-Va + Low carbon steel helical spring induced by load. The material properties for the composite material is added to the finite element model to get these results. Fig 12 shows the total deformation of the spring. Fig 13, Fig 15 and Fig 17 shows the elastic strain intensity, normal elastic strain, and shear elastic strain respectively. Fig 14 shows the equivalent stress (von mises) in the spring. Fig 16, Fig 18, and Fig 19 show the normal stress, shear stress, and stress intensity of the loaded spring.

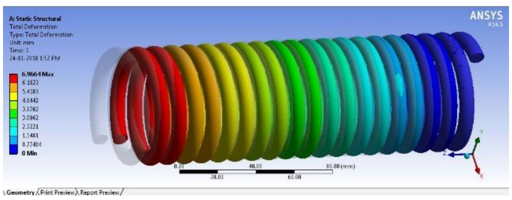


**Fig 12** Total Deformation

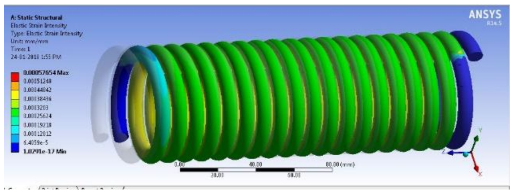


**Fig 13** Elastic Strain Intensity

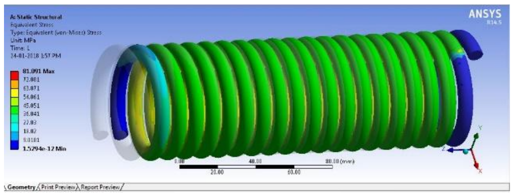


**Fig 14** Equivalent Stress (von Mises)

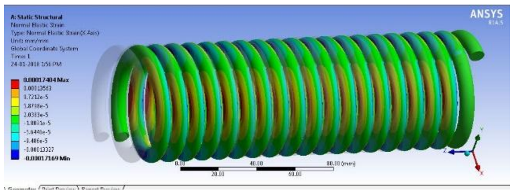


**Fig 15** Normal Elastic Strain

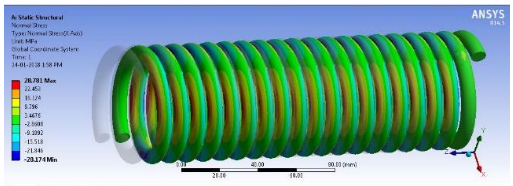


**Fig 16** Normal Stress

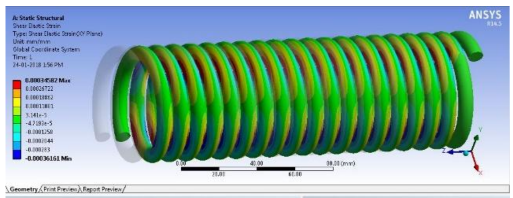


**Fig 17** Shear Elastic Strain

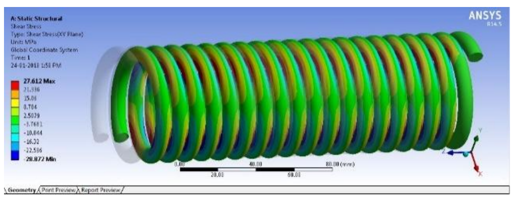


**Fig 18** Shear Stress

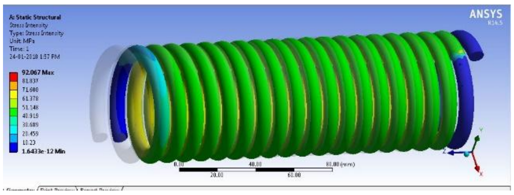

**Fig 19** Stress Intensity

**6.3. Chromium-Vanadium + Stainless Steel:**

The following figures show the results from the ANSYS solver for the other composite helical spring, which is Cr-Va + Stainless steel helical spring induced by load. The material properties for this composite material is added to the finite element model to get these results. Fig 20 shows the total deformation of the spring. Fig 21, Fig 23 and Fig 25 shows the elastic strain intensity, normal elastic strain, and shear elastic strain respectively. Fig 22 shows the equivalent stress (von mises) in the spring. Fig 24, Fig 26, and Fig 27 show the normal stress, shear stress, and stress intensity of the loaded spring.

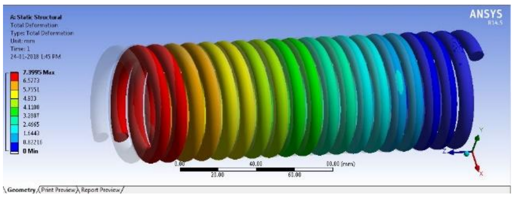

**Fig 20** Total Deformation

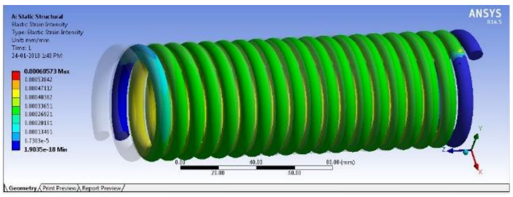

**Fig 21** Elastic Strain Intensity

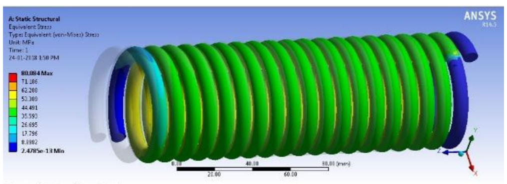

**Fig 22** Equivalent Stress (von Mises)

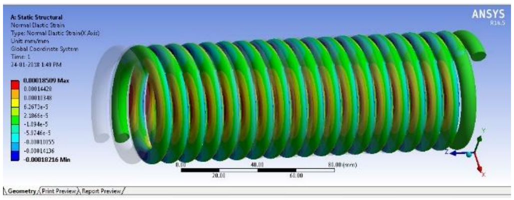

**Fig 23** Normal Elastic Strain

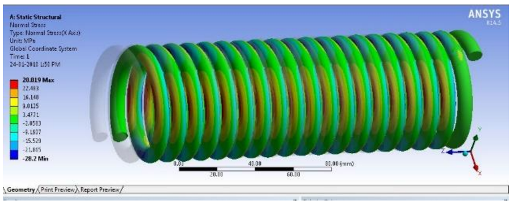

**Fig 24** Normal Stress

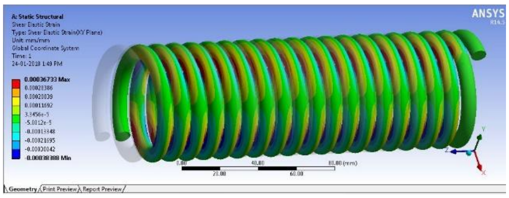

**Fig 25** Shear Elastic Strain

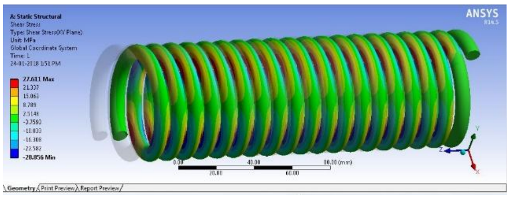

**Fig 26** Shear Stress

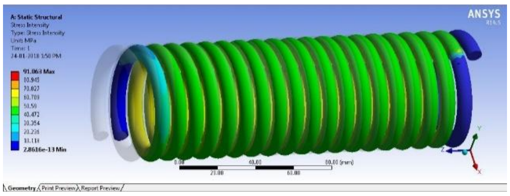

**Fig 27** Stress Intensity

### 6.4 Comparison of Results

| | Conventional steel | Cr-va+ low carbon steel | Cr-va+ stainless steel |
|---|---|---|---|
| **Total deformation mm** | 7.435 | 6.95 | 7.395 |
| **Elastic strain intensity** | 0.000618 | 0.000575 | 0.000605 |
| **Equivalent stress MPa** | 81.4 | 81.09 | 80.1 |
| **Normal elastic strain** | 0.000186 | 0.000174 | 0.000185 |
| **Normal stress MPa** | 28.765 | 28.781 | 28.815 |
| **Shear elastic strain** | 0.000369 | 0.000346 | 0.000367 |
| **Shear stress MPa** | 27.613 | 27.612 | 27.611 |
| **Stress intensity MPa** | 92.5 | 92.05 | 91 |

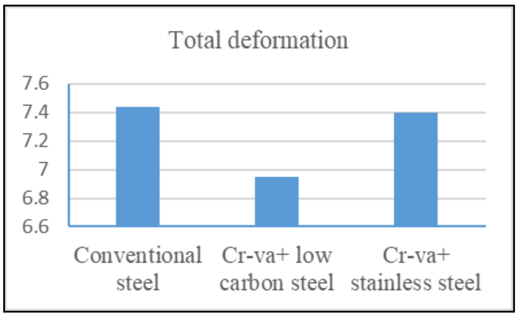


**Fig 28** Comparison of Total Deformation

The comparison graph in Fig 28 shows that Cr-Va + low carbon steel composite has higher stiffness.

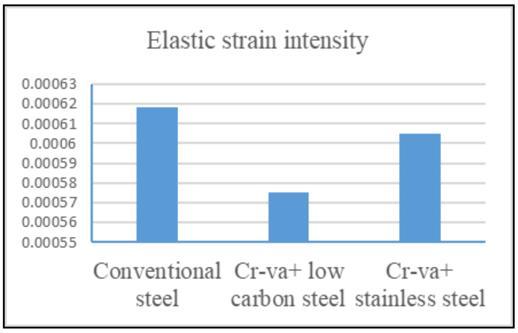


**Fig 29** Comparison of Elastic Strain Intensity

As per the comparative graph of elastic strain intensity shown in Fig 29 for the materials under study, the Cr-Va + low carbon steel composite has the lowest strain intensity. This again reflects the same low total deformation as in Fig 28.

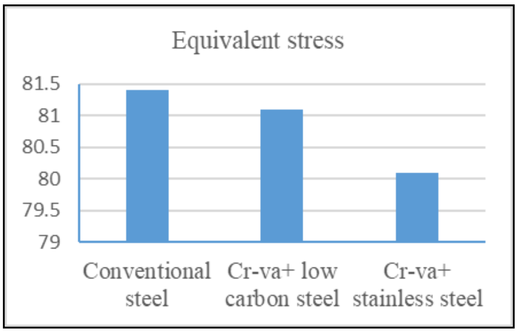


**Fig 30** Comparison of Equivalent Stress

Comparison of equivalent stress for the materials in Fig 30 shows lowest stress in the Cr-Va + stainless steel composite material.

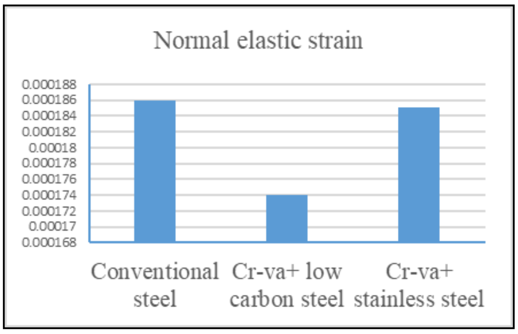


**Fig 31** Comparison of Normal Elastic Strain

Comparative graph of normal elastic strain in Fig 31 shows Cr-Va + low carbon steel gives lowest value.

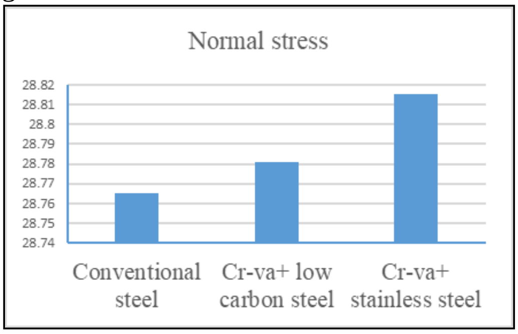


**Fig 32** Comparison of Normal Stress

Normal stress is highest in the Cr-Va + stainless steel composite, as shown in the comparative graph in Fig 32.

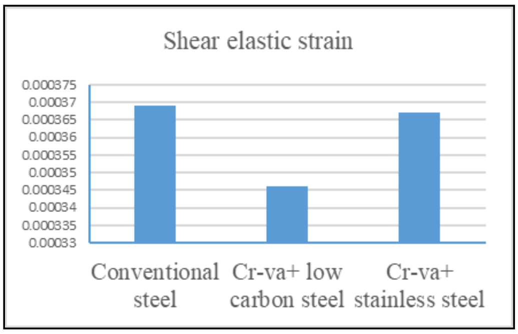


**Fig 33** Comparison of Shear Elastic Strain

The shear elastic strain for the Cr-Va + low carbon steel is the lowest in comparison. The same for the stainless steel composite and the comventional steel is more are less same. Refer Fig 33.

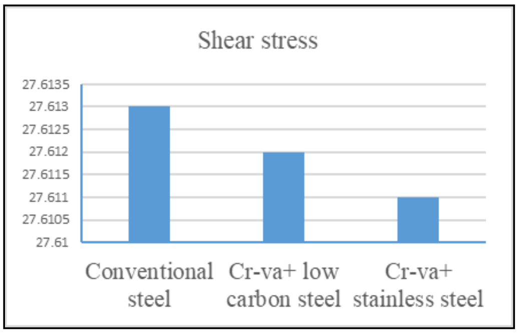


**Fig 34** Comparison of Shear Stress

As shown in Fig 34, the shear stress is least in Cr-Va + stainless steel material in comparison with the other materials. This is very preferable for a helical spring, since shear stress is often the major cause of failure in helical spring.

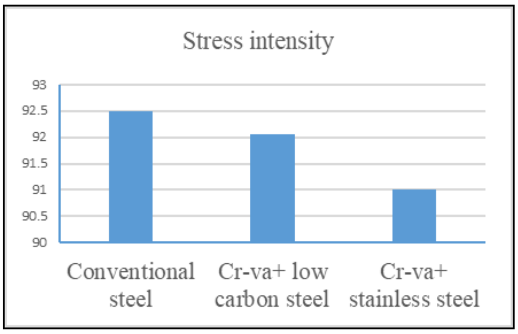


**Fig 35** Comparison of Stress Intensity

Among the materials under study, stress intensity is lowest in the Cr-Va + stainless steel composite, as shown in the comparative graph in Fig 35.

## 7 Conclusion:

To reduce the weight of the suspension spring and thereby to improve the overall performance of the vehicle, the weight of the suspension system is to be reduced by changing the helical spring material. By reducing the weight of the suspension spring the overall weight of the vehicle will also be reduced. Composite materials are selected which is composed of low carbon steel mixed with Vanadium and Chromium and another composite material of stainless steel with Vanadium and Chromium. Using these composite materials instead of conventional steel will reduce the weight of the suspension spring.

From the study of the results, it is apparent that the under deformation, the Cr-Va + stainless steel material has comparatively low stiffness which is preferable in helical coil springs. And this material also has low equivalent stress under load. Among the two composite materials chosen for study, Chromium – Vanadium mixed stainless steel composite material gives the most advantage for the suspension helical spring.

## 8 Scope for Future Work:

Fabrication of the composite coil springs can be computerized to reduce the price, which could also reduce the manufacturing downtime.

- In place of the using the carbon fiber mat cut into the specified sizes which can also damage the fibers, carbon fiber tapes inside the shape of the mold could be used to ease the fabrication technique.
- To improve the stiffness of the springs, hybrid springs (steel cord internal) surrounded by fibers can be fabricated.
- The existing investigation concentrates on the auto suspension. But there is scope for the fiber springs in locomotives which use a massive number of metallic springs for their suspension.
- The growing cost of metal and the increase within the basic weight of the locomotives the usage of metallic springs will force the locomotive enterprise to switch to the fiber springs in place of metal springs.
- Very few companies making metallic springs which inspire the manufacturing of fiber springs in a comparatively simple tactics. Such research is already in progress in several laboratories.

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