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Analysis of the Material Properties of Vehicle Suspension Coil Spring

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Abstract

The suspension coil spring is one of the most important components in a vehicle suspension system. Its primary function is to absorb the vibrational shocks that are occasioned by irregular road surface to provide the vehicle with stability and ride comfort. The main objective of this study is to design a suspension coil spring made of structural steel for light duty vehicles with the aim of weight and cost reduction. This study was motivated by the government of Ghana's actions to industrialise the automotive sector of the country through government policies and programs. The study made use of high carbon steel and low carbon steel as the control materials and structural steel as the implementing material. This was done to determine the suitability of structural steel for vehicle suspension coil spring. The study analysed parameters such as total deformation, equivalent Von Mises stress, maximum shear stress, and safety factor in the static structural analysis. The fatigue analysis also analysed parameters such as fatigue life and fatigue alternating stress. The results of the study revealed that the suspension spring made of structural steel has superior properties against all the parameters set for this study apart from deformation. The two control materials that are known for suspension coil spring design and manufacture have better properties to withstand deformation than the implementing material.

Keywords

Suspension Spring, Unsprung Mass, Fatigue Analysis, Structural Analysis, Ride Comfort, Vehicle Stability

1. Introduction

A coil 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 contacting surfaces. They are made of an elastic material which is formed into the shape of a helix which returns to its natural length when unloaded. Metal coil springs are made by winding a wire around a shaped former or a cylinder is used to form cylindrical coil springs. Coil springs for vehicles are typically made of hardened steel. A machine called an auto-coiler takes spring wire that has been heated so it can easily be shaped. It is then fed onto a lathe that has a metal rod with the desired coil spring size. The machine takes the wire and guides it onto the spinning rod as well as pushing it across the rod to form multiple coils. The spring is then ejected from the machine and an operator will put it in oil to cool off. The spring is then tempered to lose the brittleness from being cooled. The coil size and strength can be controlled by the lathe rod size and material used. Different alloys are used to get certain characteristics out of the spring, such as stiffness, dampening and strength. In its essence, the materials selection process, which is a critical task in modern engineering design and manufacturing, is regarded to be an information processing routine in suspension coil spring design. The engineering design process, including the selection of materials in design, is regarded to be a decision-making process in which choices are made from among the available alternatives. Development and use of a materials selection process, or materials selection processes, based on the principles of decision theory and information processing is called for. The process or processes so developed should be implemented on digital computer to take advantage of the computer's immense capacity for information processing. This would comprise an important component of computer-aided engineering [1].

Communication between the design and engineering disciplines is important, especially when related to materials and technological processes. Design has over time made use of and adapted some resources developed from the field of engineering, but also created its own. Design education placed at technical faculties is often characterized by a curriculum for materials education with a predominant focus on technical properties. Materials teaching in Industrial Design education are often pervaded by the tension between a natural scientific and engineering oriented topic taught in a design education rooted in a practice based and constructive tradition. The field of engineering, especially related to materials, could benefit from adapting these methods into their material education [2].

The selection of materials to use in the design and fabrication of springs relies on an understanding of the tensile and yield strengths of the various alloyed metals. These materials include high-carbon steels, alloy steels, stainless steels, copper-based alloys, and nickel-based alloys [3]. When choosing a brand of coil springs several issues should be addressed. Issues such as quality of the material being used, design of the spring, type of end the spring has, true rate of the spring, not just a tag denoting "theoretical" rate, correct markings, standardized testing procedures, and whether there is hidden cost in the spring purchased. Material selection is an important problem attracting theoretical and practical interest. Nowadays, a lot of materials and alloys are designed. In most alloys some properties are good and in compliance with the requirements, but some of them are not acceptable. Generally, for material selection methods, it is necessary to have unique synergy of theoretical knowledge and practical experiences data. Scientists used and developed some selection methods due to all of these [4].

All manufactured products, constructed structures, and infrastructure, everything from toys, domestic utensils, and furniture, to agricultural, commercial, and industrial machines, to roads, bridges, and dams, are made of material. Therefore, at some point in the process of engineering design, decisions have to be made as to which materials and what processes will be used in order to realize the product. The importance of materials to mankind is perhaps best underscored by the fact that epochal eras in civilization have been identified by the materials that were then in prevalent use. The Bronze Age, the Iron Age, and the Stone Age are examples of this practice [4].

If there are compromises made during selection of materials and/or manufacturing processes, and these compromises result in, or introduce, new critical parameters, conceptual solutions to these critical parameters can be pursued. If there are critical parameters in the materials and manufacturing process domains associated with the configuration being developed, then the designer can identify these and develop conceptual solutions as needed. Alternatively, the designer may decide that the critical parameters cannot be satisfied, discard the concept, and search for new concepts that are not governed by the same materials and manufacturing process related critical parameter [5]. Coil springs that are used in motor vehicles fail due to poor spring wire selection. Mechanical properties are useful to estimate how parts will behave when they are subjected to mechanical loads (forces, moments, etc.). In particular, the study is interested to know the weight and when the part will fail under different loading conditions. These include loading under tension, compression, torsion, bending, repeated cyclic loading, constant loading over long time, impact, etc. The study is interested in the hardness, and how these properties change with time. Premature fatigue failure is a common failure mode. However, the reasons for these failures may be more complex and include design deficiencies, heat treatment, steel alloy chemistry, intergranular cracking, and grain boundary embrittlement.

It is important to investigate other materials that can be used to design and manufacture automotive components to reduce weight and cost. The automotive industry in Ghana over the years has not seen any significant improvement due to low skills in the automotive value chain. This is because of lack of interest by successive governments to develop the automotive sector in Ghana. Almost every spare part or component used in the automotive industry in Ghana is from different countries such as Japan, Korea, China, and many others. The government of Ghana in recent past has initiated the drive to industrialize the automotive sector through government policies. The country is now seeing some significant growth in the automotive industry of late. For this industrialisation drive to be successful in the country, there is the need for highly skilled automotive engineers to contribute their parts in the automotive industrial revolution in Ghana and Africa as a whole. The Ghana beyond aid agenda seeks to encourage local manufacturers to use the raw materials in the country to produce products and also encourage Ghanaians and companies within Ghana to patronize locally produced goods. This study seeks to contribute to supporting governments' efforts to develop the automotive industry in Ghana. This work explores the possibility of using other materials apart from the known steel materials to design and manufacture a suspension coil spring for an internal combustion engine for the local automotive industry in Ghana. The quest of the government to industrialise the automotive industry in Ghana is a greater motivation behind this study.

2. Related Work

Suspension coil spring design has been considered by many researchers using different materials. For instance, authors in [6] indicated that, a composite material is a combination of two or more materials that results in better properties than those of individual component used alone. They explained that the main advantage of composite materials is their higher strength and stiffness, combined with low density, when compared with heavy materials, allowing for a weight reduction. Also, they possess significantly improved properties including high specific modulus, good wear resistance compared to unreinforced alloys. They observed that composite materials have lower density and elastic modulus which results in greater specific energy. Such properties make a very strong candidate in such applications due to such advantages of composite material; many researchers have taken interest in this area of composite materials. But these fiber composites are effective in light weight applications only. According to them, steel alloy was used in their study because it has high strength, low durability, availability, and cost is attractive compared to other composite materials. However, the scope of these properties can be extended by using copper matrix composite materials.

According to Lavanya, *et al.* [7], in their study into design and analysis of suspension coil spring for automotive vehicle used Chromium vanadium steel material with the properties of: Young's modulus = 207,000 MPa, Poisson ratio = 0.27, Density = 7860 kg/m^3. They also used low carbon steel material with the properties of Young's modulus = 198,000 MPa, Poisson ratio = 0.37, Density = 7700 kg/m^3. When static analysis was conducted on the suspension coil spring of the two different materials, they found that, under prescribed loads the induced stress and strains values for low carbon steel is less compared to chrome vanadium material also it enhances the cyclic fatigue of helical spring. They observed following from their results that the Von Mise stress induced in chromo vanadium steel was 12,201 MPa and for low carbon steel, the induced stress is 11059 MPa., the Von Mise strains induced in chromo vanadium steel was 0.05891 and that of low carbon steel was 0.055852, the stress intensity in chromo vanadium steel was 13,649 MPa and that of low carbon steel was 12,135 MPa and the total mechanical strain induced in chromo vanadium was 0.090332 and that of low carbon steel was 0.055852. They therefore concluded that the low carbon steel material is best suitable for production of helical springs compared to chromo vanadium steel materials which are used in motor vehicles.

In the same vein Sathish Kumar *et al.* [8] indicated that, the analysis of the suspension system was done by using static structural analysis and in the analysis, three different materials were taken to perform the static analysis. The three materials were: C40 steel, C70 steel, and Al-SiC. Their results indicated that, the load carrying capacity is more in Al-SiC (m-3) than C40 and C70 steel. They further indicated that this is because the yield compression value and ultimate compression is more in Al-SiC than other materials. The composite material has high stiffness to load ratio naturally since the composite material can be used to withstand load and vibration in the suspension system. The increase in the ultimate compression strength of the material helps the material to withstand the applied forces and to endure the stresses induced in them, so the material to be chosen should have high corrosion resisting properties. The preparation of Al-SiC composite is done by giving an external compressive pressure since it makes the grains to closely pack. The small grains size will make to high bonding which has more strength to carry the load. Hence, they concluded that, by comparing the results for all the three materials, the stress value is less for Al-SiC composite than C40 & C70 Steel.

There are different types and approaches of shock absorbing materials and their nature under different conditions, and by studying all the types, it was observed that Beryllium Copper is having greater strength and having more shock absorbing capacity than other conventional materials. So, it can be used as an alternative option in future for replacement of conventional suspension with more advantage. It was also observed from the results that Beryllium Copper (ASTM B197) is found to be the most optimistic material from the above all of the other materials because of the following reasons: Evaluating the strength of design, the structural analysis on the shock absorber was carried out in Ansys 14.5 by considering various materials like Stainless Steel, Beryllium Copper, Inconel Alloy, chrome silicon and carbon spring. Equivalent stress and deformations were noted for different load conditions. Its elastic properties are also far better than the rest of them. It could sustain maximum shear stress up to 350.75 MPa. It has the least axial deformation of about 12.15 mm. It takes the least time to return to its mean position once experienced by compression or expansion [9].

In the view of Alejandro Perez [10] in his study into an investigation of automotive springs: ageing effects, opined that virtually any material can be used to make springs, however the ideal material needs to have a high ultimate strength, a high yield point and a low modulus of elasticity, in order to provide maximum energy storage. Possible alternative materials include high strength steels, glass fibre reinforced polymer (GFRP), titanium alloys, glass, and nylon, among others. In his view the choice for most applications tends to be limited to plain carbon steels, alloy steels, stainless steels, high-nickel steels, and copper-based alloys. Most spring materials are manufactured according to American society for testing and material (ASTM), British standard (BS) or Deutsches institute for naming (DIN) specifications. Provided the material is not stressed beyond the elastic limit, the usual type of spring will have a straight-line load verse deflection diagram. Important aspects in spring design include determination of the spring material and dimensions. This is in order to ensure the spring will not fail due to either static or variable loads. One requirement for springs design is that it will not buckle or deform under the load within allowable limits. The material natural frequencies of vibration, are generally, sufficiently higher than the frequency of motion the springs will control. Since all materials deform with load, in a spring the parameter of this feature is called spring rate.

Author in [11] design asuspension coil spring in vehicles using finite elements method and concluded that, the simulation and analysis of coil or helical spring which is the main part in the suspension system in modern vehicles were carried out by using Solid works 2018 and Ansys 14. Three different materials were chosen to manufacture the spring under various values of loads. The results showed that the less value of total deformation happened in spring made of carbon composite for all the values of load. The deformation reduced by 15% in carbon composite comparing with the deformation in steel and reduced by about 54% comparing with total deformation in copper alloy. The deformation, strain, stress, and shear stress increased by increasing the load. They indicated that the stress and shear stress are approximately the same for the three materials under the same loading conditions. They therefore concluded that the carbon composite is the suitable material to fabricate the coil spring in the suspension system in automobiles. Carbon composite has many advantages for the suspension system such as reduce weight and high strength in spite of its cost.

In their design and analysis of suspension system, authors in [12] opined in their results that the stress and strain response of spring behaviour were observed under prescribed or expected loads and also the stress and strains values for low carbon structural steel was less when compared with chrome vanadium material. In a similar instance, authors in [13] indicated that their general review of mechanical springs used in Automobile's suspension system was one of the important considerations in spring design is the choice of the spring material. Springs are usually made from alloys of steel. The most common spring steels are music wire, oil tempered wire, chrome silicon, chrome vanadium, and 302 and 17-7 stainless. Other materials can also be formed into springs, depending on the characteristics needed. Some of the most common of these exotic metals include beryllium copper, phosphor bronze, Inconel, Monel, and titanium. Titanium is the strongest material, but it is very expensive. Next come chrome vanadium and chrome silicon, then music wire, and then oil tempered wire. The stainless and exotic materials are all weaker than the rest.

In their study into fatigue life of open coil suspension springs, authors in [14] opined that for estimation of fatigue life of Chrome Vanadium, Chrome Silicon and Hard Drawn FEA gives fatigue life of 9×10^6, 5.0108×10^7 and 1.484×10^3

cycles respectively. The finite element analysis results prove that even though the maximum deflections are almost equal, but the predication fatigue life cycle is more when compared to the Chrome Vanadium and Hard Drawn steel spring. They concluded that, their result shows that the Chrome Silicon is best replacement for chrome vanadium. Four different materials like carbon steel, alloy steel, chromium vanadium steel, stainless steel with three different loads were used for the analysis. Among the above materials carbon steel material give the better stress and deformation values compared to the other three materials. Designers mostly prefer carbon steel material for vehicle suspension spring due to its material stability, ductility, and resilience by observing those analysis of stress and deformation values. They concluded by comparing analytical values with simulated values and the results were validated because the percentage of error was very low. Therefore, it is concluded that from the above simulation results carbon steel material is more stable and gives good efficiency compared to the other three materials [15].

Pawar and Desale [16] conducted a study into optimization of three-wheeler front suspension coil spring and the material they used for their study was ASTM A227. To ensured structural reliability of the spring the static stress analysis using finite element method was done in order to find out the detailed stress distribution of the spring. The stress distribution clearly shows that the shear stress having maximum value at the inner side of every coil and concluded in their study that the helical compression spring used for front suspension of the three wheeler results shows that: The feed wire length required for modified spring new design is reduced by 10%, due to the reduction in feed wire length the mass of new design reduced by 10%, due to change in stiffness the load carrying capacity of the modified spring was increased by 7% and the vertical acceleration for modified spring was close as that of existing spring so no drastic change in ride comfort and handling characteristics of the vehicle.

In common materials selection guide for springs (2020), vehicle springs are special components in the automobile suspension system. This component is subjected to by shock loads and many variable loads. It is therefore necessary to carefully select a material that will be able to withstand the above loads. **Table 1** shows some of the most common materials that are used for coil spring design and production.

3. Method and Materials

Structure steel has been selected for the design and manufacturing of the coil spring suspension for a lightweight vehicle. Structural steel is composed of Carbon 0.25%, Silicon 0.05%, Magnesium 1.6%, Potassium 0.04%, and Iron 98. 06% though these percentages nominally fluctuate depending on design and manufacturing factors. The material has a density of 7850 kg/m^3, which is relatively equal to the metals that are used for coil spring suspension. Structural steel is one of the strongest steel alloys available, making it valuable in high-stress situations. The measure of a material's resistance to deformation is given by its

Table 1. Common materials for coil springs.

Spring Material	Material Specification	Density	Tensile Strength MPa	Modulus of Elasticity (E) MPa	Application
Beryllium copper	ASTM B197	0.298	150 - 230	18.5	Good corrosion resistance, electrical conductivity, and physical strength
Chrome silicon	ASTM A401	0.284	235 - 300	30	Shock loads and moderately elevated temperature
Chrome vanadium	ASTM A231	0.284	190 - 300	30	Ideal for Shock loads and moderately elevated temperature
Inconel springs 750	AMS 5698/5699	0.298	155 - 230	31	Good corrosion resistance at moderately elevated temperature
Music wire springs	ASTM A228	0.284	230 - 399	30	Excellent surface finish
Phosphor Bronze	ASTM B159	0.320	105 - 145	15	Cold drawn. Good electrical conductivity and corrosion resistance
Stainless steel springs 316	ASTM A313	0.286	110 - 245	28	Better corrosion and heat resistance than 302
Stainless steel 302/304	ASTM A313	0.286	125 - 325	28	Cold drawn. General purpose heat and corrosion resistance
stainless steel 17-7 PH	AMS 5678	0.282	235 - 325	29.5	High strength. General purpose heat and corrosion resistance

modulus of elasticity (E) and shear modulus (G). The modulus of elasticity of structural steel is 210 GPa, and its shear modulus is 81 GPa. Generally, this steel alloy is strong and resists deformation well, which makes it suitable for designing and manufacturing of components that are expose to high stresses and loads such as coil spring suspension. When specifying an alloy, one of the most important measures is its yield strength. The yield strength of a material is defined as the maximum amount of stress that will not permanently deform the material. Structural steel alloy has tensile yield strength of 425 MPa, which means it takes 425 MPa of stress on a piece of structural steel alloy before it cannot return to its original shape. Table 2 shows the mechanical and physical properties of the selected structural steel material which is the implementing material.

The commonly known materials for coil spring suspension design and manufacture are high carbon steel, oil tempered low carbon steel, chrome silicon steel, chrome vanadium steel and stainless steel. For the purpose of this study, analysis of the coil spring suspension has been based on comparing modelled coil spring suspension made with low carbon steel and high carbon steel to a coil spring

Table 2. Properties of the structural steel.

Parameters	Value	SI Unit
Density	7850	Kg/m^3
Ultimate Tensile Strength	535	MPa
Tensile Yield Strength	425	MPa
Poisson's Ratio	0.30	
Young's Modulus	310	GPa
Shear Modulus	120	GPa
Shear strength	390	MPa
Fatigue Strength	415	MPa

suspension made with structural steel. The parameters that were considered for the static analysis are: Equivalent Von Mise stress, factor of safety, total deformation, and maximum shear stress but in the case of the fatigue analysis, the parameters that were considered are fatigue life and fatigue alternating stress. Table 3 below shows the physical and mechanical properties of the two common materials for coil spring suspension design and manufacture. These materials are the control material materials in this study.

3.1. Design Calculation

The lightweight vehicle whose suspension was modelled was Toyota corolla 2013 model. The parameters of the suspension coil spring of the Toyota corolla are as presented in Table 4. The suspension coil spring of vehicles is of varied sizes between the front and the rear. The load transfer between these two axles has the ratio (40:60). Meaning 40% of the weight of the vehicle moves to the front axle while the remaining 60% of the load goes to the rear axle. The suspension coil spring of Toyota corolla has the following dimensions.

Vehicle Engine Specification

Vehicle Model: Toyota Corolla 2013 model

Displacement: cc (cm^3)

$$\text{Volume per cylinder} = \frac{2488}{4} = 622\ \text{cm}^3 = 622 \times 10^3\ \text{mm}^3$$

Fuel type: Petrol.

Maximum power*:* 98 Kw at 3600 r.p.m.

Maximum Torque: 304 Nm at 2000 r.p.m.

Compression ratio: 16.5:1.

Number of Cylinders: 4.

Cylinder bore and Stroke: 100 mm × 114 mm.

Gearbox: 5 Speed, manual.

Solid length of the coil spring,

$$L_s = N \times d = 8 \times 11 = 88\ \text{mm} \tag{1}$$

Table 3. Properties of low carbon steel and high carbon Steel.

Materials	Tensile Yield strength (MPa)	Compressive Yield Strength MPa	Shear strength (MPa)	Density (Kg/m^3)	Poisson's ratio	Young's Modulus (MPa)
Low carbon steel	370	985	440	7870	0.290	205
High carbon steel	450	1320	520	8260	0.31	235

Table 4. Specification of the toyota corolla 2013 model coil spring.

NO.	Parameter	Dimensions in mm
1	Total number of coils, N	8
2	Total number of active coils, n	6
3	Mean diameter, D	95
4	Wire Diameter, d	11
5	Inner Diameter, D_i	84
6	Outer Diameter, D_o	106
7	Vehicle Curb Weight	1255.09 kg
8	Vehicle Gross Weight	1739.98 kg

Free length,

$$L_f = N \times d + \delta_{\max} + 0.15\delta_{\max} = 340 \text{ mm} \tag{2}$$

Spring index,

$$C = \frac{D}{d} = \frac{95}{11} = 8.64 \tag{3}$$

$$\frac{\text{Unsprung weight}}{\text{vehicle weight}} = 0.15 \tag{4}$$

$$\begin{aligned}&\text{The unsprung mass or weight of the vehicle } m_1\\&= \text{curb weight} \times 0.15 = 1255.09 \times 0.15 = 188.26 \text{ kg}\end{aligned} \tag{5}$$

$$\begin{aligned}&\text{The sprung mass or weight } m_2\\&= \text{gross weight} - \text{unsprung weight} = 1739.98 - 188.26 = 1551.72 \text{ kg full load}\end{aligned} \tag{6}$$

$$\text{Empty load} = 1255.09 - 188.26 = 1066.83 \text{ kg} \tag{7}$$

For a quarter vehicle model which has load distribution of 40:60 load transfer between the front and rear axles suspension systems. This study considered one wheel of the rear suspension systems.

Therefore,

$$\begin{aligned}&\text{Unsprung weight or mass on each of the rear wheels}\\&= \frac{188.26 \times 0.6}{2} = 56.478 \text{ kg}\end{aligned} \tag{8}$$

$$\begin{aligned}&\text{Sprung mass or weight on each of the rear wheels}\\&= \frac{1739.98}{2} = 521.994 \text{ kg}\end{aligned} \tag{9}$$

The load applied on the suspension system.

Load on suspension,

$$\begin{aligned} W &= \text{Gross weight} \times \text{acceleration due to gravity} \\ &= 1739.98 \times 9.81 = 17069.20\ \text{N} \end{aligned} \tag{10}$$

The load applied on the rear coil spring suspension is 60% of the total load on the suspension system multiply by (10).

$$W_{rs} = 60\% \times \text{total weight on suspension} = 0.6 \times 17069.20 = 10241.52\ \text{N} \tag{11}$$

The load on each suspension coil spring of the rear axle

$$= \frac{W_{rs}}{2} = \frac{10241.52}{2} = 5120.76\ \text{N} \tag{12}$$

The twisting moment,

$$T = W_{rs} \times \frac{D}{2} = 5120.76 \times \frac{95}{2} = 243.236\ \text{N} \cdot \text{m} \tag{13}$$

Torsional shear stress,

$$\tau_1 = \frac{8WD}{\pi d^3} = \frac{8 \times 5120.76 \times 95}{\pi \times 11^3} = \frac{3891777.6}{4181.459822} = 930.72\ \text{MPa} \tag{14}$$

Direct shear stress,

$$\tau_2 = \frac{4W}{\pi d^2} = \frac{4 \times 5120.76}{\pi \times 11^2} = \frac{20483.04}{380.1327} = 53.88\ \text{MPa} \tag{15}$$

$$\text{Maximum shear stress} = \tau_1 + \tau_2 = 930.72 + 53.88 = 984.6\ \text{MPa} \tag{16}$$

$$\text{Maximum shear stress} = \tau_1 - \tau_2 = 930.72 - 53.88 = 876.84\ \text{MPa} \tag{17}$$

Deflection of low carbon steel suspension coil spring, $\delta_{lcs} = \dfrac{8W_{rs}C^3 n}{dG_{lcs}}$

$$\delta_{lcs} = \frac{8 \times 5120.76 \times 8.64^3 \times 6}{11 \times 77 \times 10^9} = \frac{158531981}{8.47 \times 10^{11}} = 0.0001872\ \text{mm} \tag{18}$$

Deflection of high carbon steel suspension coil spring, $\delta_{hcs} = \dfrac{8W_{rs}C^3 n}{dG_{hcs}}$

$$\delta_{hcs} = \frac{8 \times 5120.76 \times 8.64^3 \times 6}{11 \times 79 \times 10^9} = \frac{158531981}{8.69 \times 10^{11}} = 0.0001824\ \text{mm} \tag{19}$$

Deflection of structural steel suspension coil spring, $\delta_{ss} = \dfrac{8W_{rs}C^3 n}{dG_{ss}}$

$$\delta_{ss} = \frac{8 \times 5120.76 \times 8.64^3 \times 6}{11 \times 78 \times 10^9} = \frac{158531981}{8.58 \times 10^{11}} = 0.0001848\ \text{mm} \tag{20}$$

The suspension coil spring was modelled using the above generated dimensions. The spring was modelled in Autodesk inventor as shown in **Figure 1**.

3.2. Procedure for Numerical Analysis

This section of the study was used to present the procedure for the numerical methods which includes meshing of the suspension coil spring in Ansys, grid independence test and the boundary conditions set for this study.

Figure 1. Modeled suspension coil spring in autodesk inventor.

3.2.1. Meshing of Component

Meshing is a very important step in finite element analysis such as static structural and fatigue analyses. Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements that can be used as discrete local approximations of the larger domain. The mesh size that was used in this study is mesh size 3 cm with a resolution of 6. The mesh influences the accuracy, convergence, and speed of the simulation. If meshing is accurate, then the results are also anticipated to be closer to reality. The meshing details of the model suspension coil spring for Toyota corolla 2013 model are: number of nodes 9720 and element size 1662 (**Figure 2**).

3.2.2. Boundary Conditions

The static and fatigue analyses of the suspension coil spring made with the three different materials was done in Ansys software version R19.2. The bottom part of the suspension coil spring was constraint (fixed) and a compressive load of 5120.76 N was applied at the top portion of the suspension coil spring. Compressive load was considered because; suspension coil springs are designed for the gross weight of the vehicle acting on the coil spring. The weight of the vehicle subjects the suspension coil spring to compression. The weight transfer ratio between the front and the rear axle is 40:60 respectively. The quarter vehicle model considered for this study is one of the rear suspension coil springs. The parameters that were considered during the static structural analysis were: total deformation, equivalent (Von Mises) stress, maximum shear stress and factor of safety (**Figure 3**).

3.2.3. Grid Independence Test

The mesh size of the suspension coil spring was carefully selected since the validity of the mesh can influence the results. A grid independent test was conducted for four (4) mesh sizes which were mesh sizes 2 mm, 3 mm 4 mm and 5 mm and the best mesh size which yielded the least Von Mise stress and deformation was selected as the mesh size for the analysis. The results of the grid independent tests with a resolution of six (6) are as summarized in **Table 5**.

From **Table 5**, it is evident that the mesh size that yielded the best induced Von Mise stress is mesh size 3 mm. It can further be observed from **Table 5**

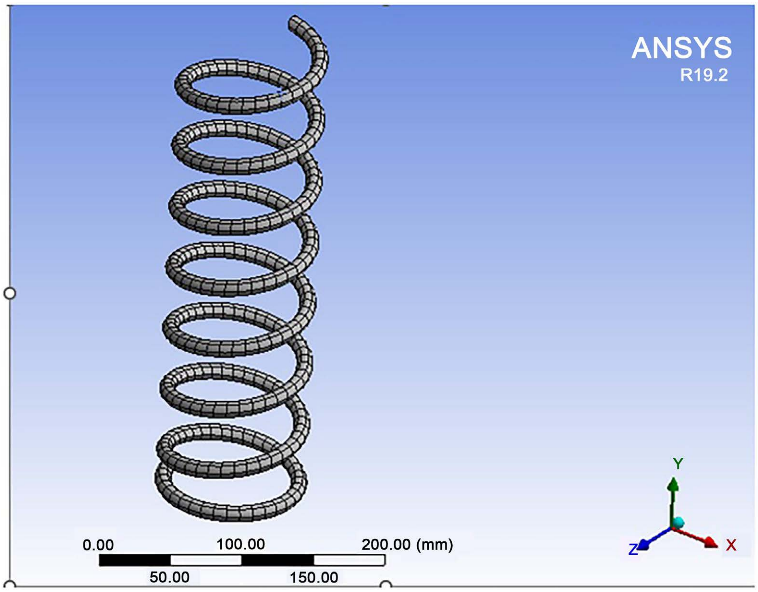

Figure 2. Meshed suspension coil spring in ansys.

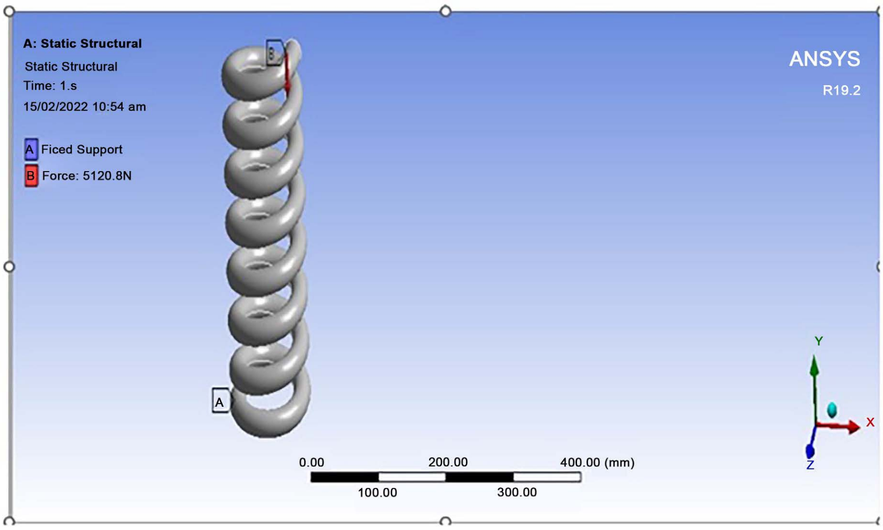

Figure 3. Boundary condition.

Table 5. Grid independence test results.

Mesh Size	Number of Nodes	Von Mises Stress	Deformation
2 mm	9345	411.78 MPa	0.216 mm
3 mm	9720	378.75 MPa	0.227 mm
4 mm	8932	420.67 MPa	0.225 mm
5 mm	9654	429.72 MPa	0.221 mm

again that all the mesh sizes yielded almost the same magnitudes of deformation with an approximation of 0.22 mm with the exception of mesh size 2 mm which produced a deformation of approximately 0.21 mm. The highest deformation of

0.22 was adopted for this experiment to ensure that the result is closer to reality. Based on Table 5 the mesh size that yielded the lowest induced Von Mise stress of 378.75 MPa and a deformation of approximately 0.23 mm is mesh size 3 mm. Hence, the model suspension coil spring of the three different materials were analysed in Ansys by using mesh size of 3.0 mm.

4. Results and Discussion

This section of the study presents the simulated results on the static structural and fatigue analysis for all the three (3) suspension coil spring materials, namely: high carbon steel, low carbon steel and the implementing material structural steel used in this study. The section also discusses and compared the results obtained from the simulation.

4.1. Static Structural Analysis of the Suspension Coil Spring

1) High carbon steel

Figure 4 shows the total deformation of high carbon steel coil spring when the maximum load of 5120.8 N was imposed on it. The main essence of suspension coil spring on lightweight vehicles is to isolate the sprung mass of the vehicle or the vehicle body from the road disturbances in order to improve ride comfort and vehicle stability. When the suspension coil spring of high carbon steel was tested using Ansys software version R19.2, it was observed that the maximum total deformation of 34.51 mm occurred at the point where the load was applied, which is the part of the coil spring that is carrying the weight of the vehicle. It was notice that, from the fourth coil counting from the top to the eighth coil suffered minimum deformations ranging from 15.338 mm to 1.8344 mm respectively. The total deformation induced in the high carbon steel suspension coil spring is significant but not enough to affect the suspension coil spring in operation. Hence, the high carbon steel suspensions coil spring will be able to withstand and carry the intended load.

Equivalent Von Mises stress is one of the most important parameters that were used to determine whether or not the suspension coil spring will fail by comparing the induced stress to the yield strength of the material. The suitability of the suspension coil spring of high carbon steel will be determined if the induced stress is less than the yield strength of the material. From Figure 5, it is observed that, the maximum Von Mise stress of 366.95 MPa occurred at the inner part of the suspension coil spring of the high carbon steel material. It was also observed that, the minimum induced Von Mise stress of 1.960 MPa occurred at the outer circumferences of the coils of the high carbon steel suspension coil spring. The maximum induced Von Mise stress of 366.95 MPa is far lesser than the tensile yield strength of 450 MPa and compressive yield strengths of 1320 MPa of the high carbon steel material. Since the suspension coil spring was design for the compressive load of the vehicle, it is therefore proper to infer that the high carbon steel suspension coil spring can endure the induced compressive stress imposed on it by the maximum load.

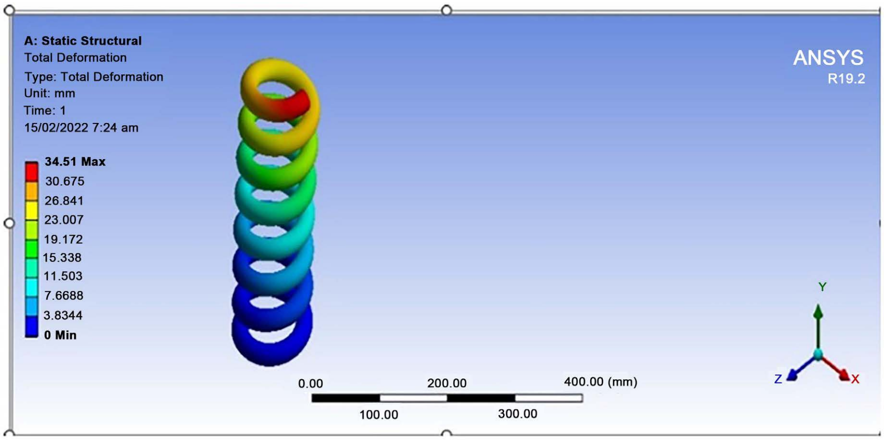

Figure 4. Total deformation of suspension coil spring.

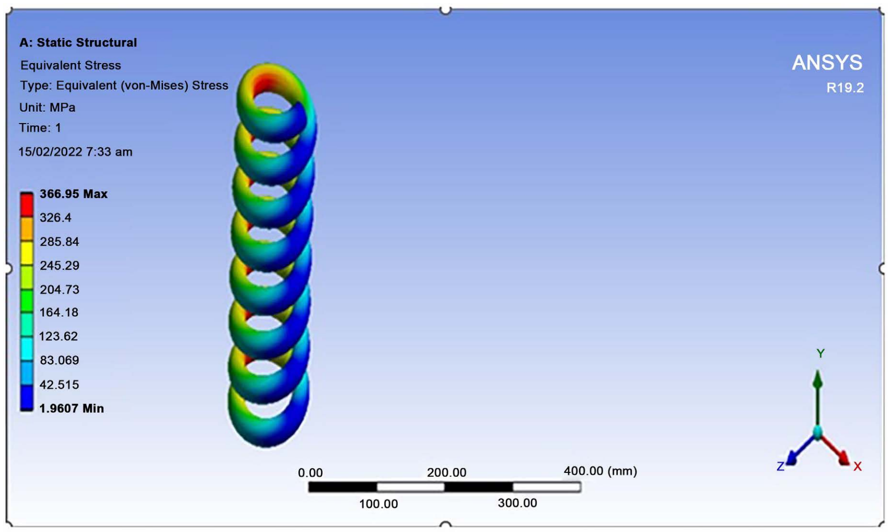

Figure 5. Equivalent Von Mises stress of coil spring.

The maximum shear stress was used to measure the possibility of shear of the high carbon steel coil spring as a result of the shear loads that the high carbon steel suspensions coil spring would be expose to. From Figure 6, it is observed that maximum shear stress of 210.9 MPa occurred at the inner circumferences of the coils of the high carbon steel suspension coil spring. The maximum shear stress has a minimum magnitude of 1.0533 MPa at the outer circumferences of the coils of the high carbon steel suspension coil spring. It was observed from Figure 6 that, the maximum shear stress induced in the high carbon steel suspension coil spring is 210.9 MPa which is far lower compared to the shear strength of the high carbon steel of magnitude 520 MPa. Therefore, the suspension coil spring made of high carbon steel will be able to withstand the maximum shear load imposed.

Figure 7 shows the factor of safety of high carbon steel suspension coil spring. The Ansys generated factor of safety of the model high carbon steel suspension coil spring has a maximum and minimum factor of safety magnitudes of 15 and

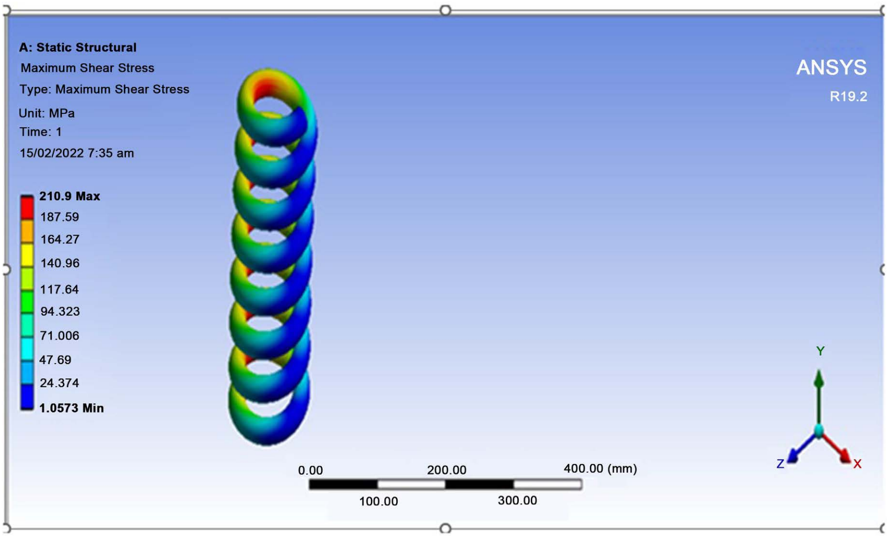

Figure 6. Maximum shear stress of spring.

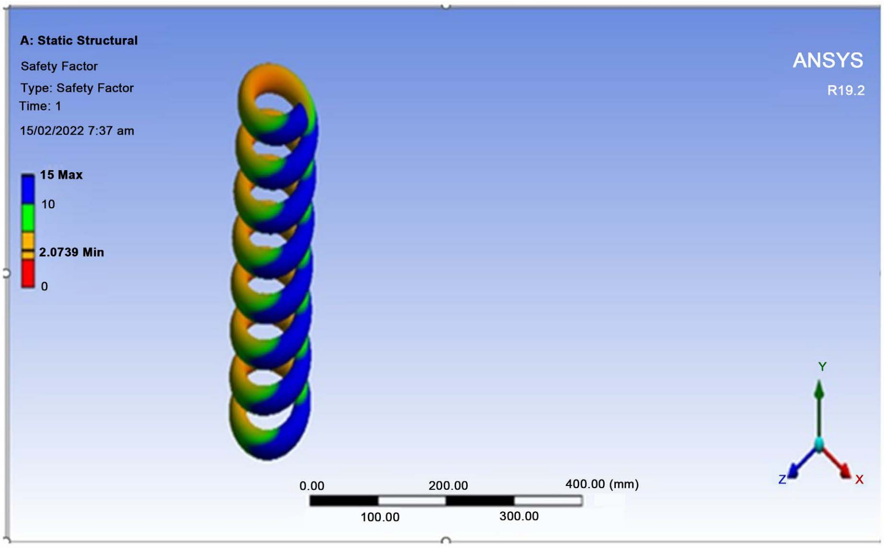

Figure 7. Factor of safety of suspension coil spring.

2.0739 respectively. It was observed that the maximum factor of safety of 15 was more pronounce at some portions of the outer coils of the suspension coil spring of the high carbon steel material. The minimum factor of safety of 2.0739 was widespread throughout the entire high carbon steel suspension coil spring.

Table 6 shows the summary of the results obtained when static structural analysis was conducted on the model high carbon steel suspension coil spring.

2) Low Carbon Steel

Figure 8 shows the total deformation of low carbon steel suspension coil spring when the maximum load of 5120.8 N was subjected on it. When the suspension coil spring of low carbon steel was tested using Ansys software version 19.2, it was observed that the maximum total deformation of 34.838 mm occurred at the point where the load was applied, which is the part of the coil

Table 6. Results for high carbon Steel suspension coil spring.

Parameters	Maximum	Minimum
Total deformation	34.51 mm	1.8344 mm
Equivalent Von Mises Stress	366.95 MPa	1.960 MPa
Maximum Shear Stress	210.9 MPa	1.0533 MPa
Factor of Safety	15	2.0739

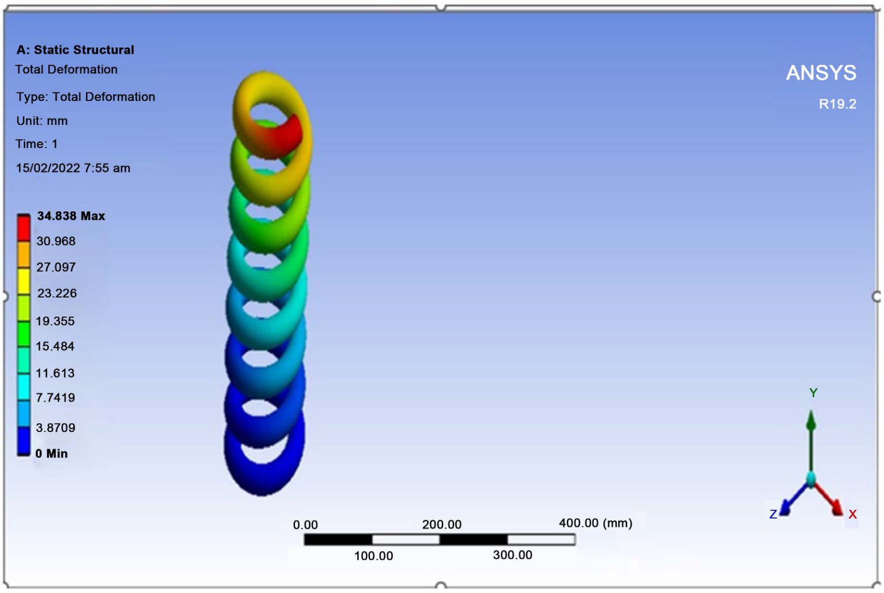

Figure 8. Total deformation of steel coil spring.

spring that is carrying the weight of the vehicle. It was notice that, from the fourth coil counting from the top to the eighth coil suffered minimum deformations ranging from 3.8709 mm to 0.00 mm respectively. The total deformation induced in the low carbon steel suspension coil spring is significant but not enough to affect the suspension coil spring in operation. Hence, the low carbon steel suspensions coil spring will be able to withstand and carry the intended load.

Figure 9 shows the Equivalent Von Mise stress induced in the low carbon steel suspension coil spring. This is one of the most important parameters that was used to measure whether or not the suspension coil spring of low carbon steel will fail by comparing the induced stress to the yield strength of the material. The suitability of the suspension coil spring of low carbon steel will be determined if the induced stress is less than the yield strength of the material. From Figure 9, it was observed that, the maximum Von Mise stress of 366.95 MPa occurred at the inner part of the suspension coil spring of the low carbon steel material. It was also observed that, the minimum induced Von Mise stress of 1.9607 MPa occurred at the outer circumferences of the coils of the low carbon steel suspension coil spring. The maximum induced Von Mises stress of 366.95 MPa is lesser than the tensile yield strength of 370 MPa and compressive yield

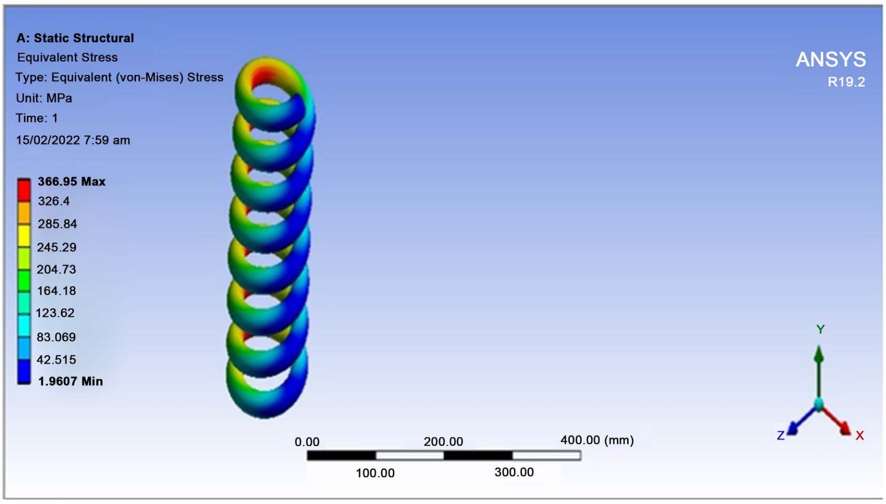

Figure 9. Equivalent Von Mises stress of coil spring.

strengths of 985 MPa of the low carbon steel material. Hence, it is convenient to say that the low carbon steel suspensioncoil spring can endure the induced stress imposed on it by the maximum load.

Figure 10 shows the maximum shear stress induced in the low carbon steel suspension coil spring. This parameter was used to predict the possibility of shear of the low carbon steel suspension coil spring as a result of the shear load imposed on it. From Figure 10, it was observed that the maximum shear stress of 210.9 MPa occurred at the inner circumferences of the coils of the low carbon steel suspension coil spring. The maximum shear stress was of minimum magnitude of 1.0573 MPa at the outer circumferences of the coils of the low carbon steel suspension coil spring. It was observed from the Figure 10 that, the maximum induced shear stress of 210.9 MPa was far lower compared to the shear strength of low carbon steel of magnitude 440 MPa. Therefore, the suspension coil spring made of low carbon steel will be able to withstand the maximum shear load imposed.

Figure 11 shows the factor of safety of low carbon steel suspension coil spring. The Ansys generated factor of safety of the model low carbon steel suspension coil spring has a maximum and minimun factor of safety magnitudes of 15 and 0.63486 respectively. It was observed that the maximum factor of safety of 15 was more pronounce at some portions of the outer coils of the suspension coil spring of low carbon steel material. The minimum factor of safety of 0.63486 was widespread throughout the entire low carbon steel suspension coil spring.

Table 7 shows the summary of the results obtained from the static structural analysis was conducted on the model low carbon steel suspension coil spring.

3) Structural Steel

Figure 12 shows the total deformation of the structural steelsuspension coil spring when the maximum load of 5120.8 N was subjected on it. When the suspension coil spring of structural steel was tested using Ansys software version 19.2, it was observed that the maximum total deformation of 36.740 mm

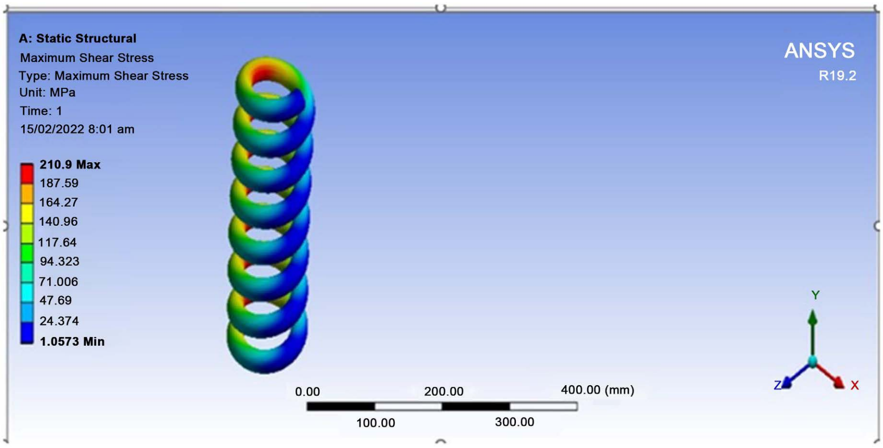

Figure 10. Maximum shear stress of coil spring.

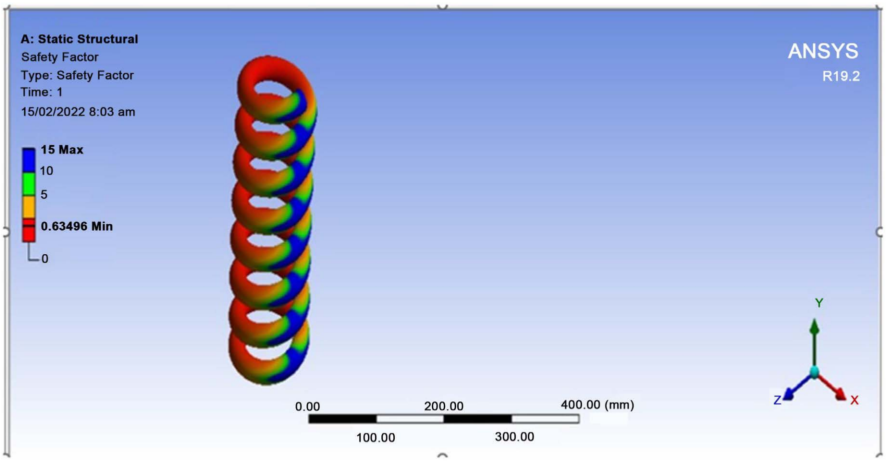

Figure 11. Factor of safety coil spring.

Table 7. Results for low carbon Steel suspension coil spring.

Parameters	Maximum	Minimum
Total deformation	34.838 mm	0.00 mm
Equivalent Von Mises Stress	366.95 MPa	1.9607 MPa
Maximum Shear Stress	210.9 MPa	1.0573 MPa
Factor of Safety	15	0.63486

occurred at the point where the load was applied, which is the part of the coil spring that is carrying the weight of the vehicle. It was notice that, from the fourth coil counting from the top to the eighth coil suffered minimum deformations ranging from 4.0832 mm to 0.00 mm respectively. The total deformation induced in the structural steel suspension coil spring is significant but not enough to affect the suspension coil spring in operation. Hence, the structural steel suspensions coil spring will be able to withstand and carry the intended load.

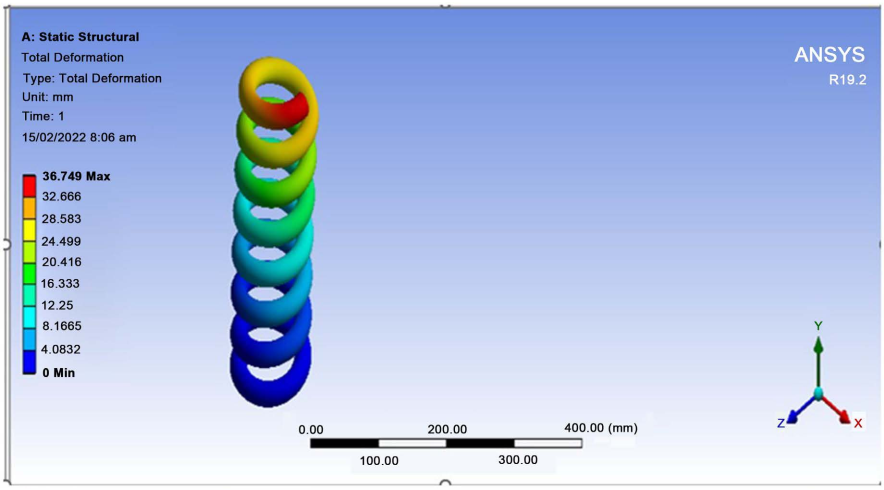

Figure 12. Total deformation of coil spring.

Figure 13 shows the Equivalent Von Mise stress induced in the structural steel suspension coil spring. This is one of the most important parameters that was used to measure whether or not the suspension coil spring of structural steel will fail by comparing the induced stress to the yield strength of the material. The suitability of the structural steel suspension coil spring will be determined if the induced stress is less than the yield strength of the material. From **Figure 13**, it was observed that, the maximum induced Von Mise stress of 366.8 MPa occurred at the inner part of the suspension coil spring of the structural steel material. It was also observed that, the minimum induced Von Mises stress of 1.9917 MPa occurred at the outer circumferences of the coils of the structural steel suspension coil spring. The maximum induced Von Mises stress of 366.8 MPa is lesser than the tensile yield strength of 425 MPa of the structural steel material. Hence, it is convenient to say that the structural steel suspension coil spring can endure the induced stress imposed on it by the maximum load.

Figure 14 shows the maximum shear stress induced in the structural steel suspension coil spring. This parameter was used to predict the possibility of shear of the structural steel coil spring as a result of the shear load imposed on it. From **Figure 14**, it was observed that the maximum induced shear stress of 210.81 MPa occurred at the inner circumferences of the coils of the structural steel suspension coil spring. The maximum shear stress was of minimum magnitude of 1.0757 MPa at the outer circumferences of the coils of the structural steel suspension coil spring. It was observed from the test conducted that, the maximum induced shear stress of 210.81 MPa was far lower compared to the shear strength of structural steel of magnitude 390 MPa. Therefore, the suspension coil spring made of structural steel will be able to withstand the maximum shear load imposed.

Figure 15 shows the factor of safety of structural steel suspension coil spring. The Ansys generated factor of safety of the model structural steel suspension coil spring has a maximum and minimum factor of safety magnitudes of 15 and

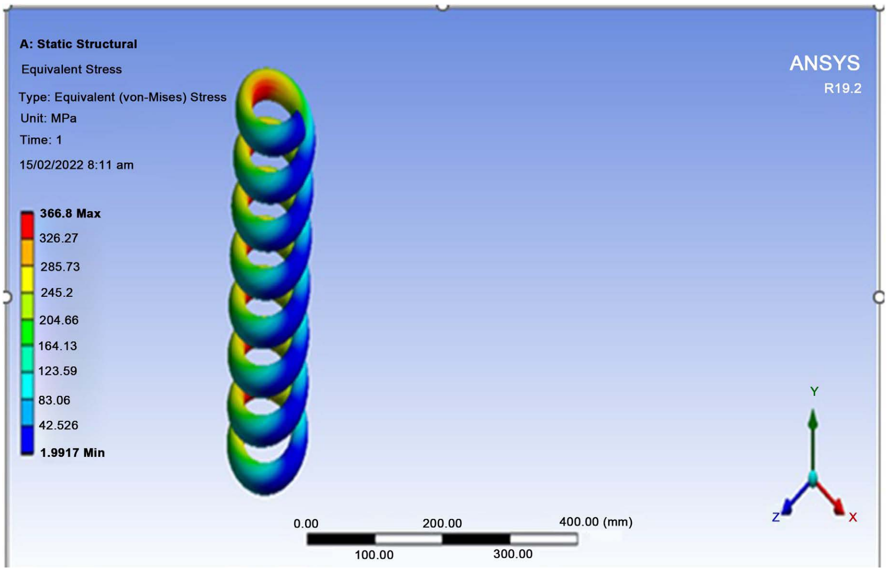

Figure 13. Equivalent Von Mises stress of coil spring.

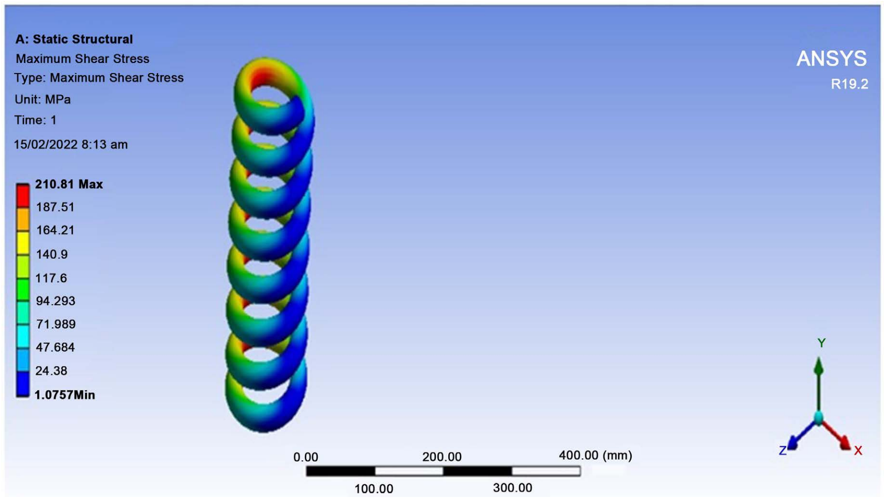

Figure 14. Maximum shear stress of coil spring.

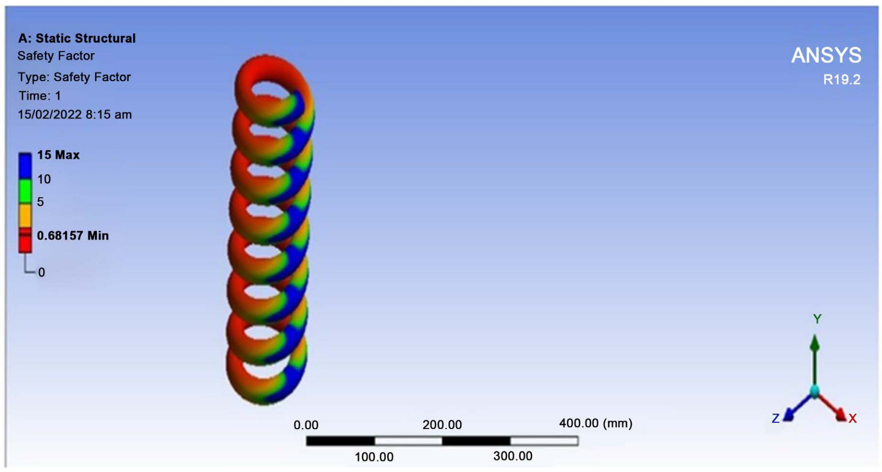

Figure 15. Factor of Safety of coil spring.

0.68157 respectively. It was observed that the maximum factor of safety of 15 was more pronounce at some portions of the outer coils of the suspension coil spring of structural steel material. The minimum factor of safety of 0.68157 was widespread throughout the entire structural steel suspension coil spring.

Table 8 shows the summary of the results obtained from the static structural analysis was conducted on the model structural steel suspension coil spring.

4.2. Comparison of Static Structural Analysis

This section compares all the parameters set for this study by comparing the same parameters for the three different suspension coil spring materials.

Figure 16 shows the total deformation results of the static structural analysis of the suspension coil springs of the three different materials, namely: high carbon steel, low carbon steel and structural steel. The static structural results on total deformation presented in Figure 16 shows that, the total deformation of high carbon steel suspension coil spring of 34.51 mm representing 32.53%, low carbon steel suspension coil spring yielded a total deformation of 34.84 mm representing 32.84% and structural Steel suspension coil spring yielded a total deformation of 36.74 mm also representing 34.63%. It was observed that, high carbon steel suspension coil spring and low carbon steel suspension coil spring deformed less compared to the structural steel suspension coil spring. In terms of deformation, the implementing material which is structural steel has weak properties to resist deformation compared to high carbon steel which has superior properties to resist deformation than all the selected materials. The deformations suffered by all the three materials of the suspension coil springs were significant because, Ansys software treats the closing of the pitch gaps as a deformation. These deformations were observed not to be significant enough to affect the suspension coil springs in practice; hence the suspension coil spring made of high carbon steel, low carbon steel and structural steel can be described to be fit for purpose and has the ability to withstand the weight of the vehicle during vibration.

Figure 17 presents the results of the equivalent Von Mise stress, of the model suspension coil springs of the three different materials, namely: high carbon steel, low carbon steel and structural steel. One of the most important parameters for this study is the Von Mises stress. This is one of the parameters that was used to determine whether the suspension coil springs will either fail or not when compared with the yield strengths of the materials. When the induced equivalent (Von Mise) stress is equal or more than the yield strength of the material, then the component made of that material cannot withstand the loading condition, hence the design will fail. But when the Von Mise stress induced in the suspension coil springs of the three different materials were compared as shown in Figure 17, the results shows that the induced Von Mise stress yielded by high carbon steel suspension coil spring was 366.95 MPa representing 33.34%, low carbon steel suspension coil spring yielded the same Von Mises stress of 366.95 representing the same percentage as the high carbon steel

Table 8. Results for structural Steel suspension coil spring.

Parameters	Maximum	Minimum
Total deformation	36.740 mm	0.00 mm
Equivalent Von Mises Stress	366.8 MPa	1.9917 MPa
Maximum Shear Stress	210.81 MPa	1.0757 MPa
Factor of Safety	15	0.68157

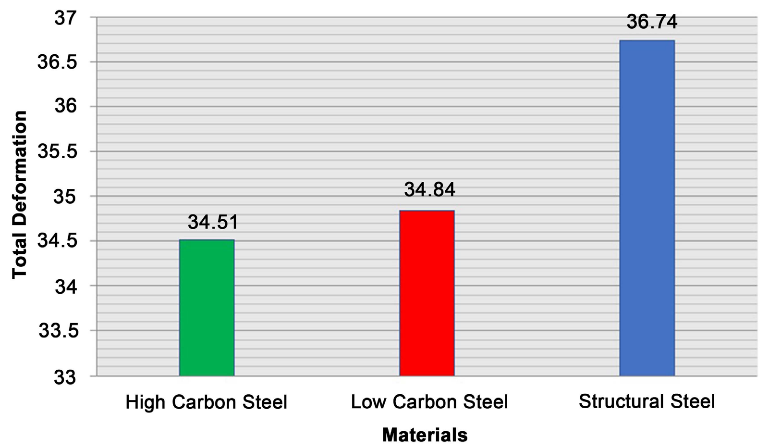

Figure 16. Comparison of total deformation of static analysis.

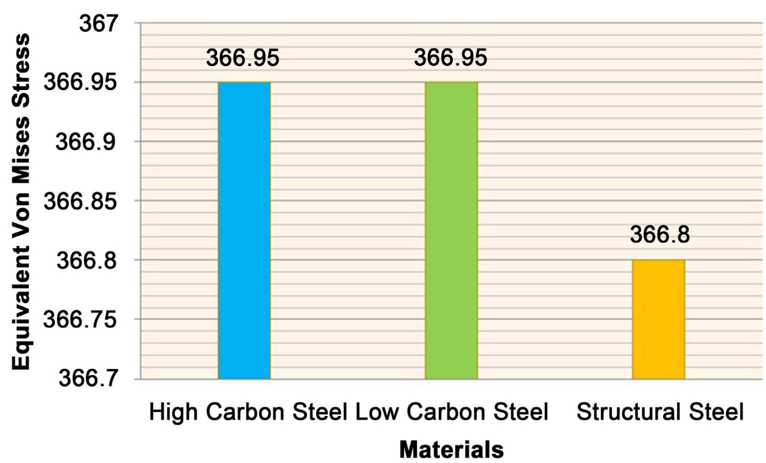

Figure 17. Comparison of equivalent Von Mises stress.

suspension coil spring and Structural steel suspension coil spring yielded 366.8 representing 33.32% of the total Von Mise stress induced in the suspension coil springs made with the three different materials. It was observed from the above data that, high carbon steel suspension coil spring and low carbon steel suspension coil spring yielded the same but highest induced Von Mise stress of 366.95 MPa representing 33.34% while structural steel suspension coil spring yielded the lowest induced Von Mises stress of 366.8 MPa representing 33.32. It is, therefore, safe to say that the implementing material's suspension coil spring which is structural steel suspension coil spring has superior properties to resist stress than high carbon steel and low carbon steel suspension coil springs. The induced Von Mise stresses in the suspension coil springs of the three different materials were observed to be far lower than the yield strengths of all the materials. Again, the percentage difference of the induced Von Mises stresses between high carbon steel suspension coil spring, low carbon steel suspension coil spring and structural steel suspension coil spring was insignificant; hence all the three materials are good for suspension coil springs design and manufacture.

When the maximum shear stress induced in the suspension coil springs made with the three different materials, namely; high carbon steel, low carbon steel and structural steel were compared the chart in **Figure 18** shows that, high carbon steel suspension coil spring yielded a maximum shear stress of 210.9 MPa representing 34% , low carbon steel suspension coil spring yielded the same value of 210.9 MPa representing the same percentage yielded by high carbon steel and the structural steel suspension coil spring yielded a maximum shear stress of 210.8 MPa representing 33% of the total maximum shear stress induced in the three suspension coil springs. It was observed from the above data that, the suspension coil springs made of high carbon steel and low carbon steel yielded the highest maximum induced shear stress of 210.9 MPa while the suspension coil spring made of structural steel yielded the minimum or the lowest maximum shear stress of 210.8 MPa. The comparison shows that, structural steel which is the implementing material in this study has superior properties to withstand shear load more than high carbon steel and low carbon steel. It was again observed that, there was no significant percentage difference between all the three materials, hence all the suspension coil springs made from the three selected materials can withstand the load imposed.

Table 9 shows the comparison of the factor of safety values of all the three materials, namely: high carbon steel, low carbon steel and structural steel. **Table 3** revealed that, all the suspension coil springs made of high carbon steel; low carbon steel and structural steel have the same maximum factor of safety values of 15. Hence, the suspension coil springs made of high carbon steel, low carbon steel and structural steel have good enough factor of safety to be able to carry the intended load.

4.3. Fatigue Analysis of the Suspension Coil Spring

1) Structural steel

Figure 19 shows the fatigue life of structural steel suspension coil spring when subjected under the maximum cyclic loading. The three main inputs for fatigue life analyses are processed using various life estimation tools depending on whether the analysis is for crack initiation, total life, and crack growth. This analysis employed total fatigue life to determine the life of the suspension coil springs. From **Figure 19**, it can be observed that, the maximum fatigue life cycle of the structural steel suspension coil spring was 1×10^6 cycles which are about one million cycles. These maximum life cycles were observed to be more pronounced at the outer coils of the suspension coil spring, but the inside of the coil

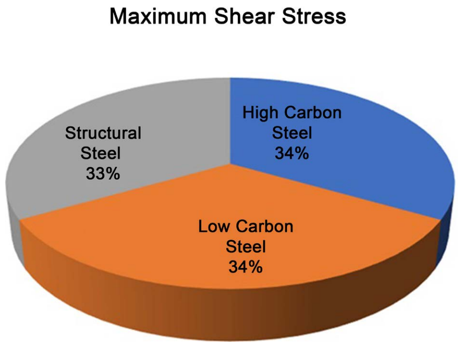

Figure 18. Comparison of maximum shear stress.

Table 9. Comparison of factor of safety.

Materials	Safety Factor	
	Maximum	Minimum
High Carbon Steel	15	2.0739
Low Carbon Steel	15	0.63486
Structural Steel	15	0.68157

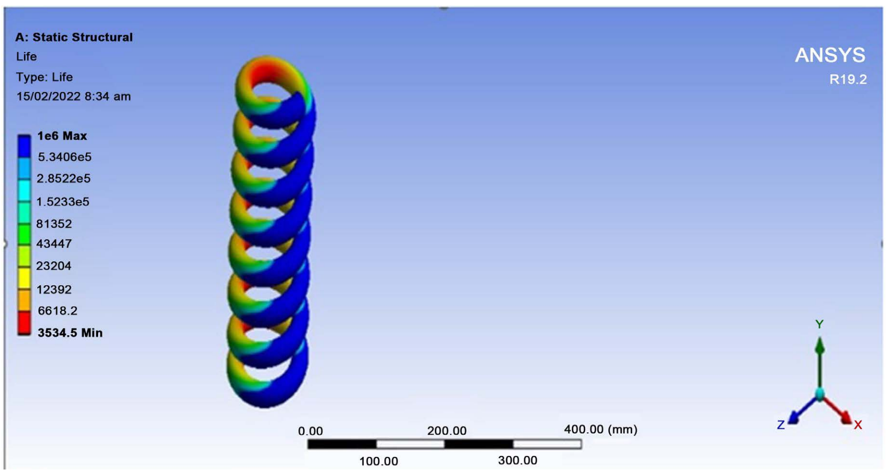

Figure 19. Fatigue Life of the coil spring.

spring appeared to have minimum life. This result makes the structural steel material which is the implementing material one of the best materials for suspension coil spring design and manufacture since it has high fatigue life cycles.

Figure 20 shows the fatigue factor of safety of stuctural steel suspension coil spring. The Ansys generated fatigue factor of safety of the model structural steel suspension coil spring has a maximum fatigue factor of safety value of 15 and minimun fatigue factor of safety magnitude of 0.23501. It was observed that the maximum fatigue factor of safety of 15 appeared at some few areas at the outer coils of the suspension coil spring. This shows that, structural steel suspension coil springs has not too good fatigue factor of safety. This result is at variance with the factor of safety obtained when static structural analysis was conducted on the same material.

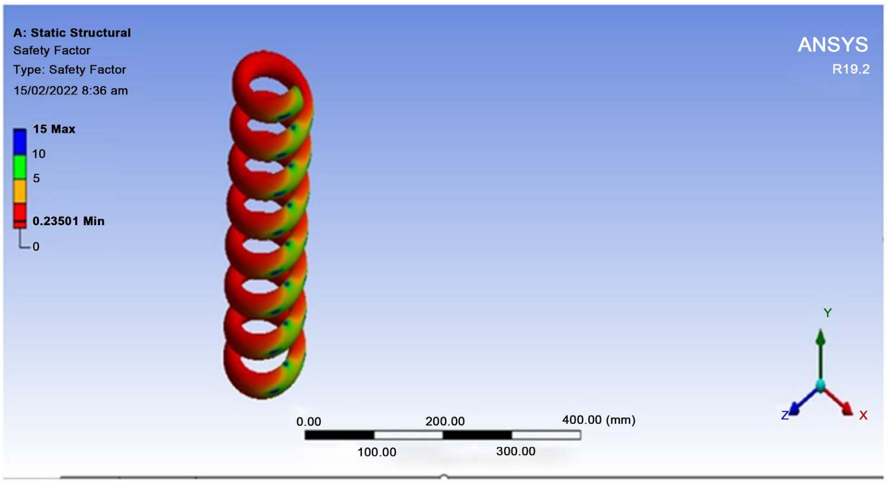

Figure 20. Fatigue Factor of safety of coil spring.

Figure 21 shows the fatigue alternating stress of structural steel coil spring. Fatigue alternating stress is also one of the most important parameters that was used to determine the suitability of a material for a particular design. It is the stress that is induced in a material as a result of a variable load or cyclical loading. Fatigue impact is variable; hence the material should have good strength enough to be able to withstand the shock impact. It was observed from **Figure 21** that, the maximum fatigue alternating stress of 366.8 MPa occurred at the outer circumferences of the coils of the suspension coil spring while the minimum fatigue alternating stress of 1.9917 MPa occurred at the inner part of the coils of the suspension coil spring. It was observed that the maximum direct stress obtained when static structural analysis was conducted was the same compared to the maximum fatigue alternating stress. Hence, the suspension coil spring made of structural steel has the capacity to withstand both the direct and fatigue alternating stresses.

2) High carbon steel

Figure 22 shows the fatigue life of high carbon steel suspension coil spring when subjected under the maximum cyclic loading. This analysis employed total fatigue life to determine the life of the suspension coil springs. From **Figure 22**, it was observed that, the maximum fatigue life cycle of the high carbon steel suspension coil spring was zero cycles which means that high carbon steel has no life or the fatigue life of high carbon steel couldn't be predicted.

Figure 23 shows the fatigue factor of safety of high carbon steel suspension coil spring. The Ansys generated fatigue factor of safety of the model high carbon steel suspension coil spring has a maximum fatigue factor of safety value of 15 and minimun fatigue factor of safety magnitude $2.3665E^{-10}$. It was observed that the minimum fatigue factor of safety of $2.3665E^{-10}$ was widespread across the entire high carbon steel suspension coil spring. This shows that, high carbon steel suspension coil springs has a very bad fatigue factor of safety. This result is at varience with the factor of safety obtained when static structural analysis was conducte on the same material.

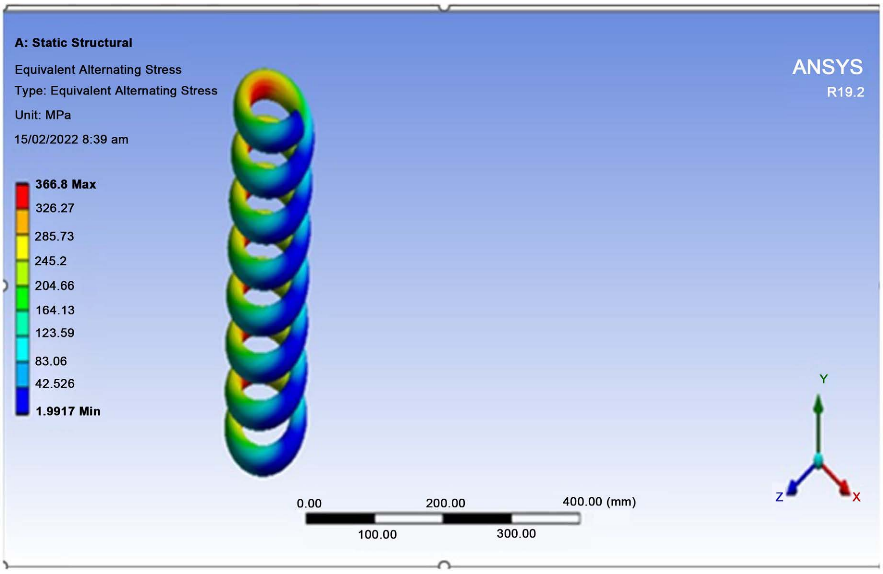

Figure 21. Fatigue alternating stress of coil spring.

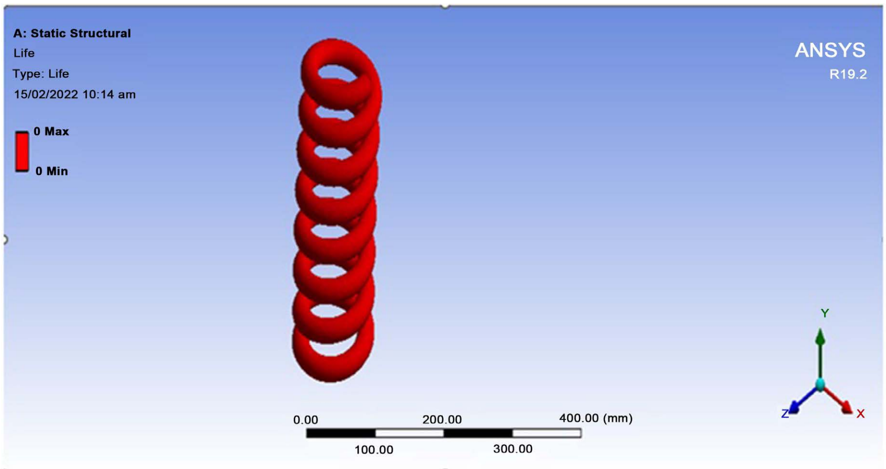

Figure 22. Fatigue Life of high coil spring.

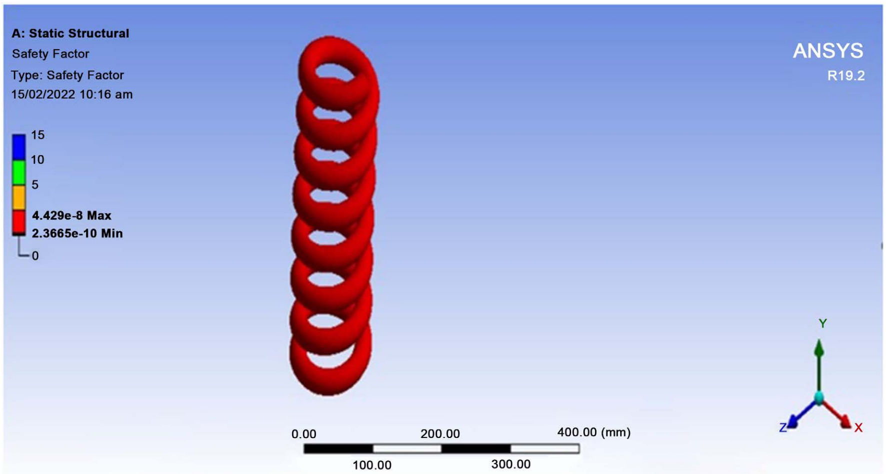

Figure 23. Fatigue factor of safety of coil spring.

Figure 24 shows the fatigue alternating stress of high carbon steel coil spring. Fatigue alternating stress is also one of the most important parameters that was used to determine the suitability of a material for a particular design. It is the stress that is induced in a material as a result of a variable load or cyclical loading. Fatigue impact is variable; hence the material should have good strength enough to be able to withstand the shock impact. It was observed from Figure 24 that, the maximum fatigue alternating stress of 366.95 MPa occurred at the outer circumferences of the coils of the high carbon steel suspension coil spring while the minimum fatigue alternating stress of 1.9607 MPa occurred at the inner part of the coils of the suspension coil spring. It was observed that the maximum direct stress obtained when static structural analysis was conducted was the same compared to the maximum fatigue alternating stress. Hence, the suspension coil spring made of high carbon steel has the capacity to withstand both the direct and fatigue alternating stresses.

3) Low carbon steel

Figure 25 shows the fatigue life of low carbon steel suspension coil spring when subjected under the maximum cyclic loading. This analysis employed total fatigue life to determine the life of the suspension coil springs. From Figure 25, it was observed that, the maximum fatigue life cycle of the low carbon steel suspension coil spring was zero cycles which means that low carbon steel has no life or the fatigue life of low carbon steel cannot be predicted.

Figure 26 shows the fatigue factor of safety of low carbon steel suspension coil spring. The Ansys generated fatigue factor of safety of the model low carbon steel suspension coil spring has a maximum fatigue factor of safety value of $4.864E^{-17}$ and minimun fatigue factor of safety magnitude $2.5989E^{-19}$. It was observed that the minimum fatigue factor of safety of $2.5989E^{-19}$ was widespread across the entire low carbon steel suspension coil spring. This shows that, low carbon steel suspension coil springs has a very bad fatigue factor of safety. This

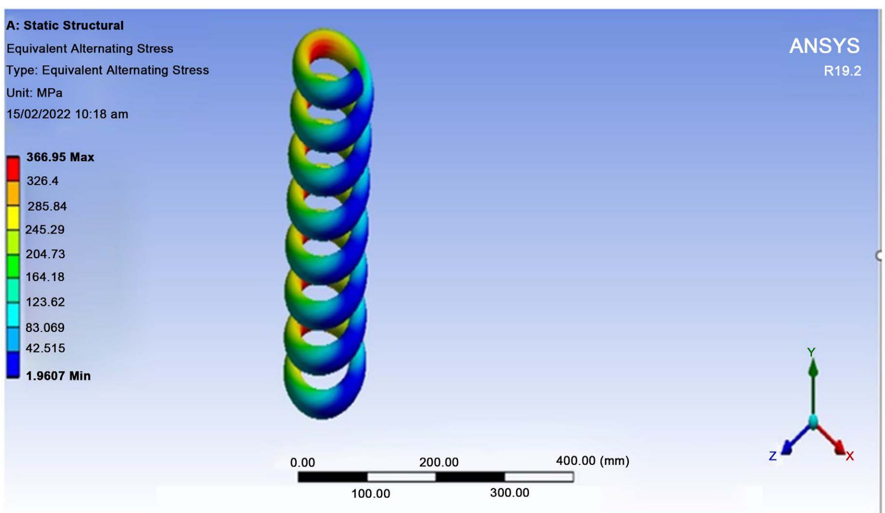

Figure 24. Fatigue alternating stress of coil spring.

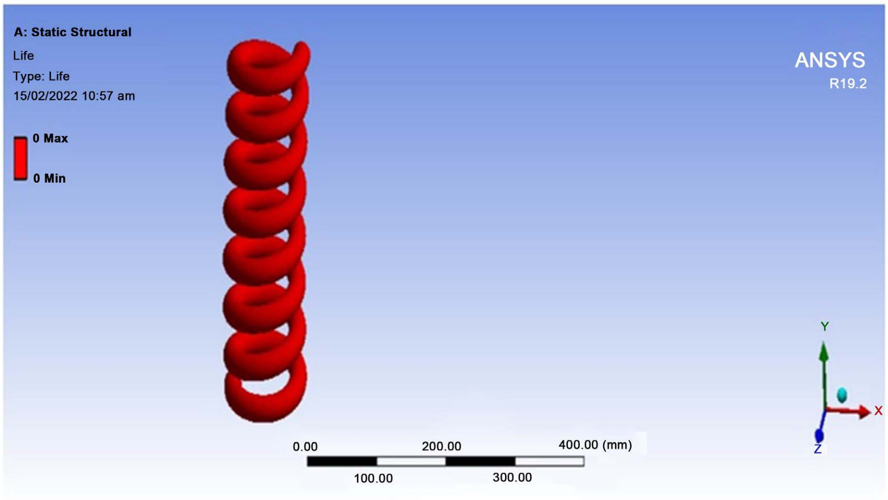

Figure 25. Fatigue life of low carbon steel coil spring.

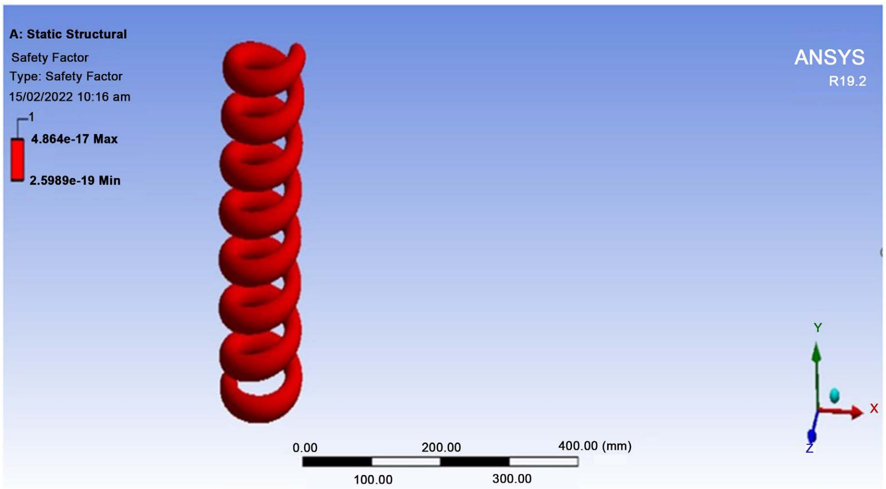

Figure 26. Fatigue factor of safety of coil spring.

result is also at varience with the factor of safety obtained when static structural analysis was conducted on the same material.

Figure 27 shows the fatigue alternating stress of low carbon steel suspension coil spring. It is the stress that is induced in a material as a result of a variable load or cyclical loading. Fatigue impact is variable; hence the material should have good strength enough to be able to withstand the shock impact. It was observed from Figure 27 that, the maximum fatigue alternating stress of 366.95 MPa occurred at the outer circumferences of the coils of the low carbon steel suspension coil spring while the minimum fatigue alternating stress of 1.9607 MPa occurred at the inner part of the coils of the suspension coil spring. It was observed that the maximum direct stress obtained when static structural analysis was conducted was the same compared to the maximum fatigue alternating stress. Hence, the suspension coil spring made of low carbon steel has the capacity to withstand both the direct and fatigue alternating stresses.

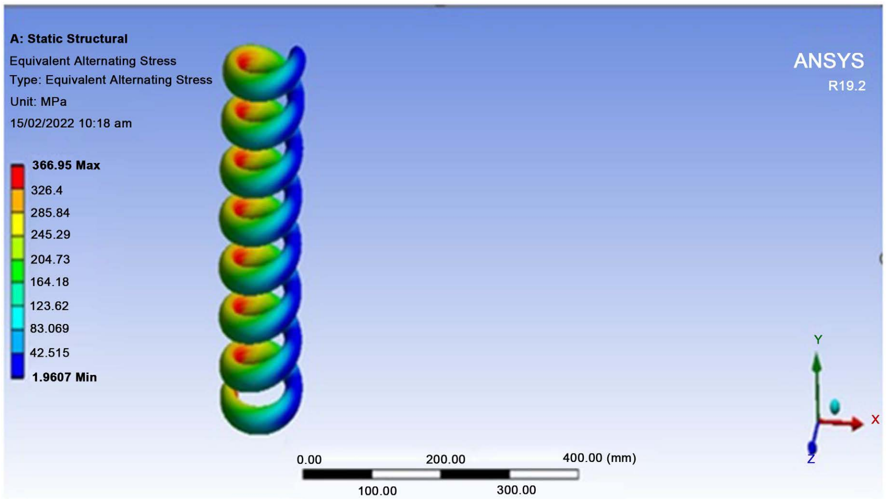

Figure 27. Fatigue alternating stress.

5. Conclusion

This study examined two methods of analysis: static structural analysis and fatigue analysis. Under the static structural analysis, the following parameters were considered for three suspension coil springs made from different materials, high carbon steel, low carbon steel, and structural steel: total deformation, equivalent Von Mises stress, maximum shear stress, and the factor of safety. The suspension coil spring is designed to withstand shocks from irregular road surfaces and various road conditions, necessitating the use of robust materials. Typically, suspension coil springs are constructed from materials like high carbon steel, low carbon steel, and chrome vanadium steel. The primary objective of this study was to assess the suitability of structural steel for designing suspension coil springs in lightweight vehicles. These suspension coil springs were modeled using Autodesk Inventor and then exported to Ansys for further analysis. In the Ansys software, a static load of 51,208 N was applied to all suspension coil springs made of high carbon steel, low carbon steel, and the chosen material, structural steel. The study compared the specified parameters across all three suspension coil springs constructed from these different materials. This study concludes that, except for deformation, structural steel, the chosen material, exhibits superior properties in all the parameters compared to high carbon steel and low carbon steel. Additionally, structural steel is lighter than high carbon steel and low carbon steel. Therefore, future studies on suspension coil spring design should consider not only the design and manufacturing of the suspension coil spring but also conducting further tests by installing a prototype suspension coil spring in a real vehicle to identify any design-related issues. Modal analysis should also be conducted to assess any oscillatory frequency concerns with the suspension coil spring's design.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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