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Finite element analysis of a FeC, Cr-V and Al 7075-T6 leaf springs for light vehicle suspension system

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Abstract

This study has become very necessary because of the current condition of the roads in our country. The study is conducted to come out with an alternative best, cheapest, and available material for the design of leaf springs to prevent or reduce vehicle breakdown due to the breaking of the leaf spring on roads. Weight reduction is one of the main focuses of automobile manufacturers in this modern era. The objective of this study is to model and analyze a leaf spring for a light vehicle suspension system with Plain Carbon Steel (FeC), Chromium Vanadium steel (Cr-V), and Aluminum 7075-T6 as the implementing material using Finite Element Method (FEM). Aluminum 7075-T6 is very strong, and durable and will help in weight reduction since the axle leaf spring arrangement also adds weight to the vehicle. The study showed that, when the applied load of 3359.94 N was induced on the aluminum 7075-T6 leaf spring, the result was superior compared to the other materials with the same loading condition. The aluminum 7075-T6 leaf spring was observed to withstand deformation, strain, and stress better due to its superior properties. The study concluded that Aluminum 7075-T6 material should be adopted for manufacturing leaf springs and similar automobile components since it is light, strong, and can withstand greater forces.

Keywords: Suspension Leaf spring; Glass/Epoxy; Equivalent Elastic Strain; Equivalent Elastic Stress; Maximum shear stress; Finite Element Method (FEM)

1. Introduction

Several components in the suspension system are employed to make the vehicle driving very comfortable. Leaf springs are one of the important parts used in the suspension system in a vehicle that can also improve the comfortability of the vehicle. It is designed to absorb shock and shaking from the road to prevent direct impact to the occupants and the vehicle body. It also improves the ability to grip the tire on the road surface and to support the weight of the vehicle entirely. It is well known that; springs are designed to absorb and store energy and then releasees it slowly [1].

In this modern world, the automobile manufacturing industries are focusing on weight reduction and fuel consumption. Weight reduction can be achieved primarily by using a good material that is durable and lighter. A good material plays a very significant role in the direction of design optimization and better manufacturing processes. Generally, materials used in automobile manufacturing come in different texture and density, it also has greater specific strain energy capacity in the operations of axle springs for effective performance in automobile vehicles on the various road conditions. This specific function occurs in leaf springs which are designed to absorb and store energy and releases slowly. The ability of the leaf spring to store and absorb more quantity of strain energy guarantees the comfort and

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reliability of its application. However, in most cases, leaf springs are deprived of the above operating qualities and resulting in the failure of the expected operational systems. The main effect is that, it is either broken or over-stretched. In view of this, the research focuses on the cause of the breaking and stretching of this unit in the automotive suspension system by using a more durable material.

In furtherance, weight reduction in automobiles starts from the suspension systems such as the axle and leaf spring [2]. Fiberglass-reinforced plastic (FRP), springs Glass/Epoxy, C- Glass/Epoxy, S- Glass/Epoxy, etc. are examples of composed materials used in the manufacturing of leaf springs. The replacement of steel with an optimally designed composite material leaf spring can provide 92% weight reduction [3]. [4] optimized the development of 56SiCr7 leaf spring and micro-hardness measurements show surface degradation effects. [5] optimized the key design parameters of EN45A flat leaf spring and developed a leaf spring program used to improve various parameters of the leaf spring quickly and reliably. [5] adopted carbon/glass epoxy composite as a leaf spring material and analyzed the leaf spring by using Ansys software. The design and experimental study of the leaf spring showed that the carbon/glass epoxy-reinforced polymer is a better material that can be used for lightweight vehicles. The analysis of load-carrying capacity, stiffness, and weight savings were compared with that of steel leaf springs. The study showed that the composite material spring had 67.35% less stress, 64.95% higher stiffness, and 86.98% higher natural frequency as compared to the existing steel leaf spring [6]. [7] carried out numerical simulations using both the small and large deflection theories to calculate the stress and the deflection of a parabolic leaf spring. Non-linear analysis is found to have a significant effect on the beam's response under a tip load. It was seen that the actual bending stress at the fixed end calculated by the nonlinear theory was 3.39 % less in comparison to a traditional leaf spring having the same volume of material.

The main aim of this study is to model and perform static structural analysis of leaf springs made of FeC, Cr-V and Al 7075-T6 materials for light vehicle suspension system. No engineering design can fully accomplish its purpose when the appropriate material is not used, hence, the need for this study.

2. Materials and Method

2.1. Materials

Aluminum is a silver-white metallic material used in so many places, especially during manufacturing. Aluminum 7075-T6 is an alloy material that is resistant to corrosion, lighter in weight, and has good tensile strength. It has high stiffness, toughness, and ductile properties and is not readily tarnished. Aluminum 7075-T6 has an alloy content of 0.3% carbon, 0.05% silicon, 2.1% magnesium and 6% iron. Plain carbon steel and chromium-vanadium steel materials were used as benchmark materials to compare the results.

Table 1 Properties of the Materials

Properties	Plain carbon steel	Chromium vanadium steel	Aluminum 7075 -T6
Density	7860 kg/s	7860 kg/m3	2810 Kg/m3
Yield strength	960 MPa	776 MPa	480 MPa
Tensile strength	520 MPa	940 MPa	560 MPa
Shear modulus	82.7 GPa	82.7 GPa	26 GPa
Young modulus	13.5 GPa	210 GPa	70 GPa
Poisson ratio	0.31	0.31	0.32

2.2. Method

The leaf spring was modeled using Autodesk inventor profession 2016 software. ANSYS workbench was used to simulate and analyze the modeled assigned with, plain carbon steel, chromium-vanadium steel and aluminum 7075-T6 materials.

2.2.1. Load Acting on Leaf Spring

Deriving the expressions for the forces acting on the leaf spring are shown as:

The minimum load acting on the leaf spring (F_{min})is given by;

$$F_{min} = \left(\frac{W_k}{\frac{4}{2}}\right) \times g\ N \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where,
W_k = weight
g = acceleration due to gravity

The maximum load acting on the leaf spring (F_{max}) is given as: $F_{max} = \left(\frac{wg}{\frac{4}{2}}\right) \times gN \ldots\ldots\ldots(2)$

Where:

W_g = Gross weight

$$Z = 2L - \left(\frac{2}{3} \times x\right) \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

Where:
Effective length of leaf spring (L)
Span of the leaf spring (Z)
X = distance between U – bolt
2L = total length of the top leaf spring

$$L = (\left(\frac{Z}{2}\right) m \ldots\ldots\ldots\ldots\ldots\ (4)$$

Effective length of the leaf spring (L)
Deflection of the leaf spring (δ)

Minimum effective length of leaf spring (δmin) is given by

$$\delta min = \frac{12 \times Fmin \times L^3}{E \times b \times t^3[(2 \times ng)+(3 \times nf)]} \ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

Where:
F_{min} = minimum load acting on the leaf spring = 1982.85N
L = Effective length (L) = 562.67m
nf = number of full-length leaves = 2
ng = number graduated leaves = 3
t = thickness of the leaf = 12mm
e = young modulus of the material
b = width of the leaf = 60 x 10^3 m

Maximum effective length of leaf spring (δmax) is obtain using

$$\delta max = \frac{12 \times Fmax \times L^3}{E \times b \times t^3[(2 \times ng)+(3 \times nf)]} \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Bending stress on the leaf spring is given by

Minimum bending stress on leaf spring δmim is obtained by

$$\delta mim = \frac{18 \times Fmim \times L}{b \times t^2[(2 \times ng)+(3 \times nf)]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (7)$$

Maximum bending stress on the leaf spring δmaxis governed by

$$\delta max = \frac{18 \times Fmax \times L}{b \times t^2 \times [(2 \times ng)+(3 \times nf)]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

The determination of the spring leaf length.

$$\text{Length of graduated leaf} = \frac{\text{effective length} \times x}{n-1} + \text{ineffective length} \quad \text{............(9)}$$

The ineffective is the distance between centre of the U-bolt

Distance between center of U- bolt = 82

N= total number of leaves = $n_f + n_g = 2 + 3 = 5$

X = position of the leaf.

[8] proposed a calculation method of the stiffness of the taper-leaf spring based on the combine superposition method and the finite difference method.

Table 2 Parameters Used for Modelling the Leaf Springs

Parameters	Value
Width of the leaf spring (d)	60 mm
Thickness of leaf (t)	12 mm
Outer diameter of the leaf eye	54 mm
Inside diameter of the leaf eye	42 mm
Camber of leaf spring	110 mm
Length of smaller leaf	307.068mm
Length of second leaf (2nd)	532.136mm
Length of third leaf (3rd)	757.204mm
Length of fourth (4th)	982.272mm
Length of fifth (5th)	1207.34mm

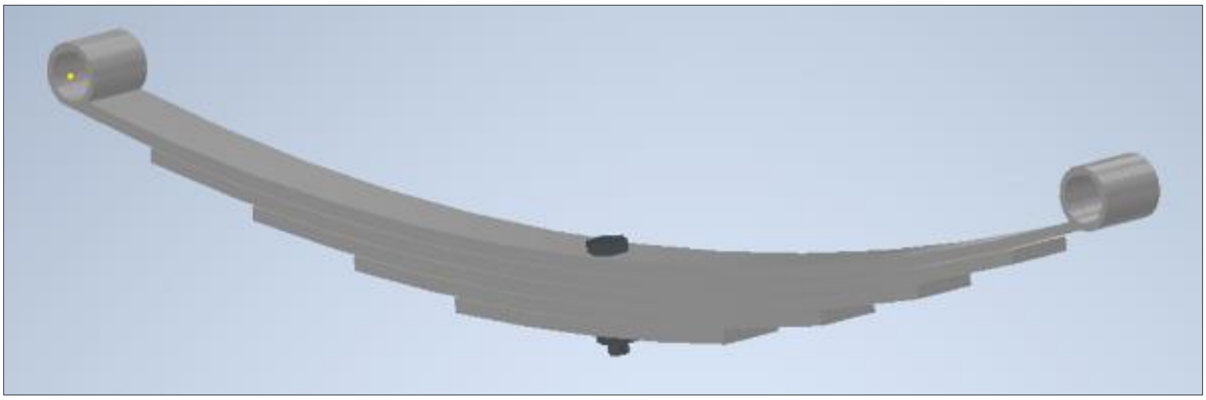

Figure 1 Modeled Leaf Spring

Figure 1 shows the modeled leaf spring before plain carbon steel, chromium-vanadium steel, and aluminum 7075-T6 materials were individually assigned to it for the simulation.

2.2.2. Meshing of Component

The meshing details of the model suspension leaf spring are as follows: 18,549 nodes and 2,724 elements. The meshing of the Nissan Hard Body suspension leaf spring is shown in Figure 2.

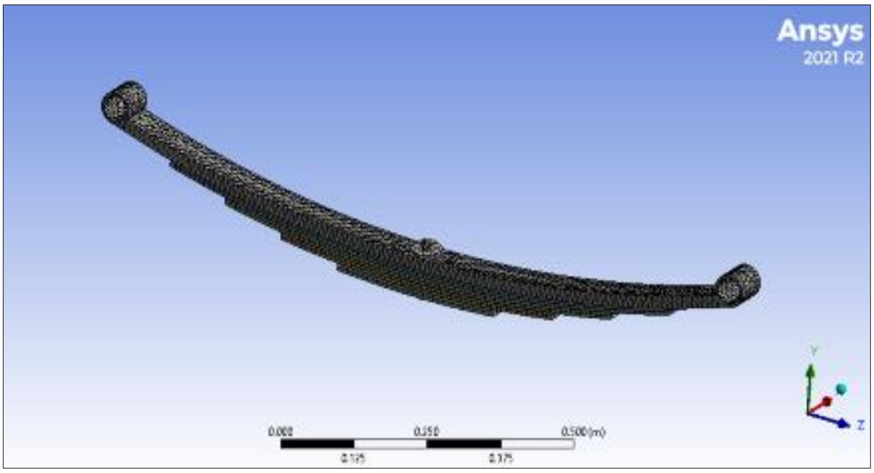

Figure 2 Meshed Geometry

2.2.3. The Boundary Conditions for the Suspension Leaf spring

The maximum load of 3359.94 N was applied on top of the suspension leaf spring. The load was applied on top because, in practice, the weight of the vehicle exerts a force downward when it is applied.

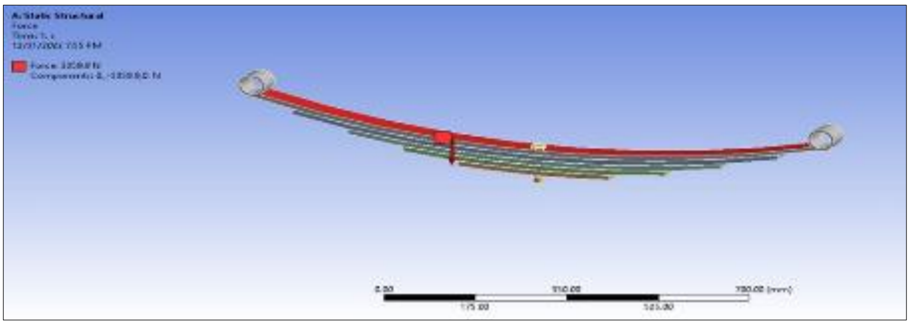

Figure 3 Boundary Conditions

3. Results

3.1. Total Deformations of Leaf Springs

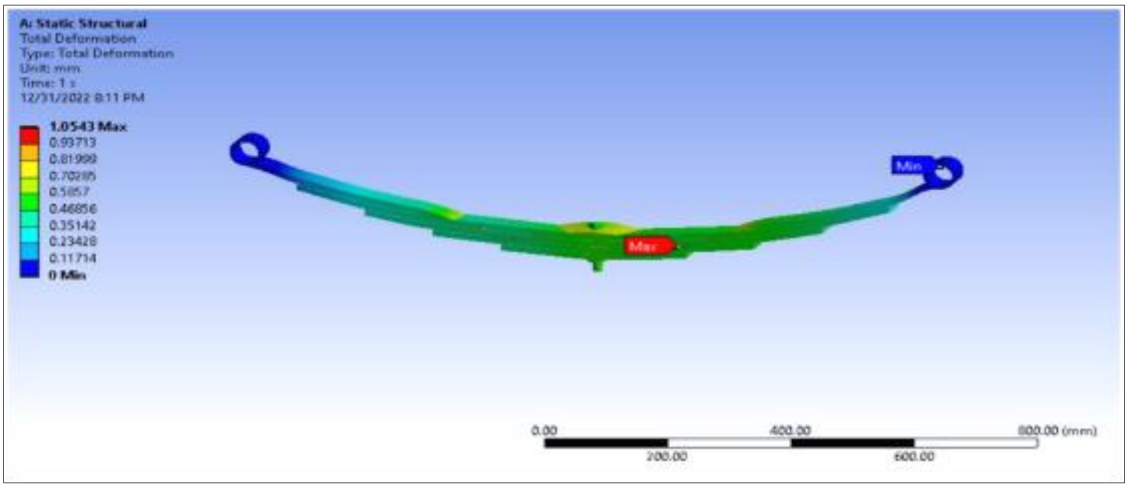

Figure 4 Plain Carbon Steel Model

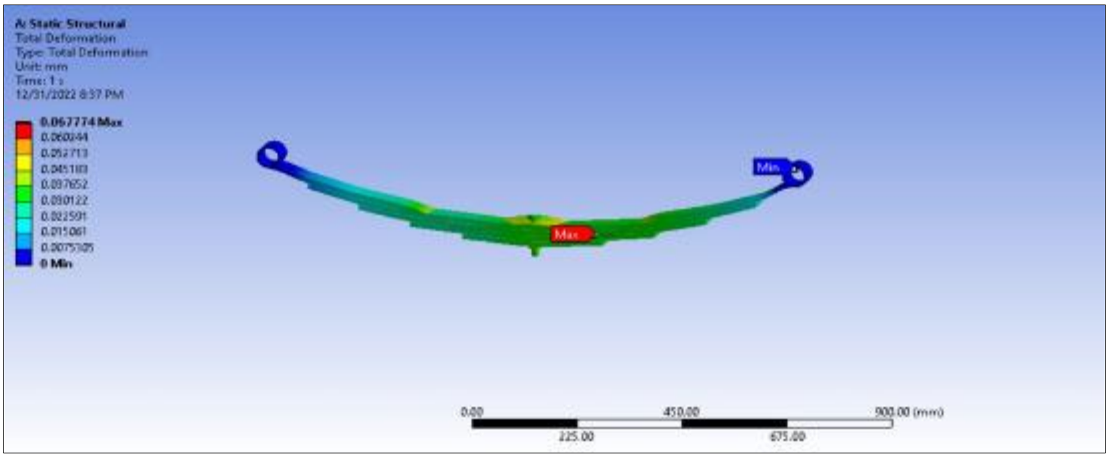

Figure 5 Chromium Vanadium Model

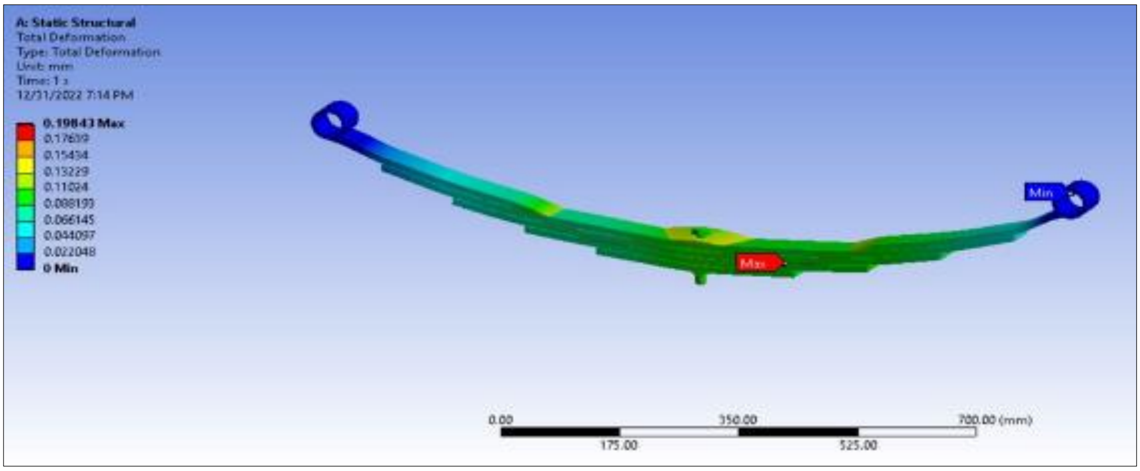

Figure 6 Aluminum 7075-T6 Model

3.2. Equivalent Elastic Strain of leaf springs

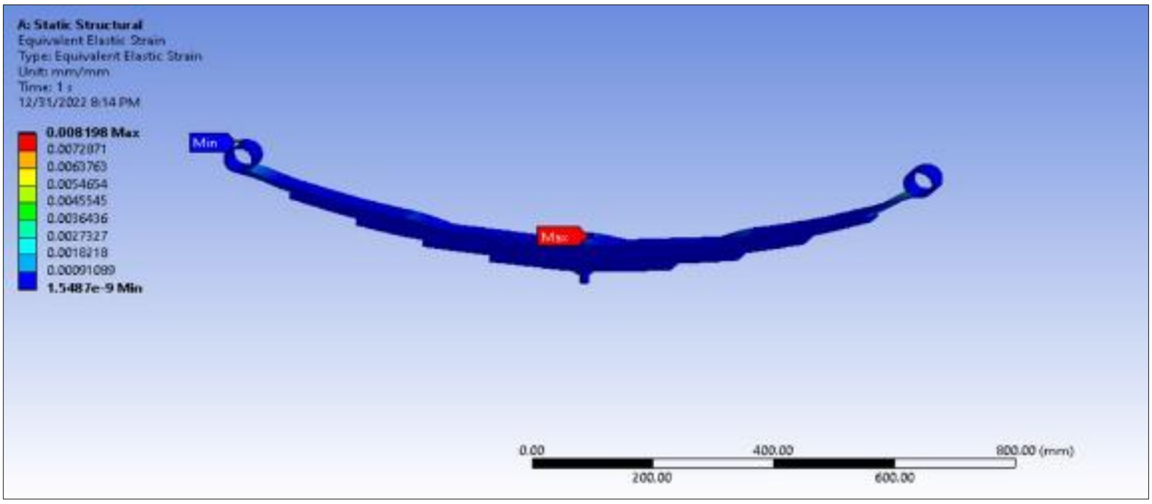

Figure 7 Plain Carbon Steel Model

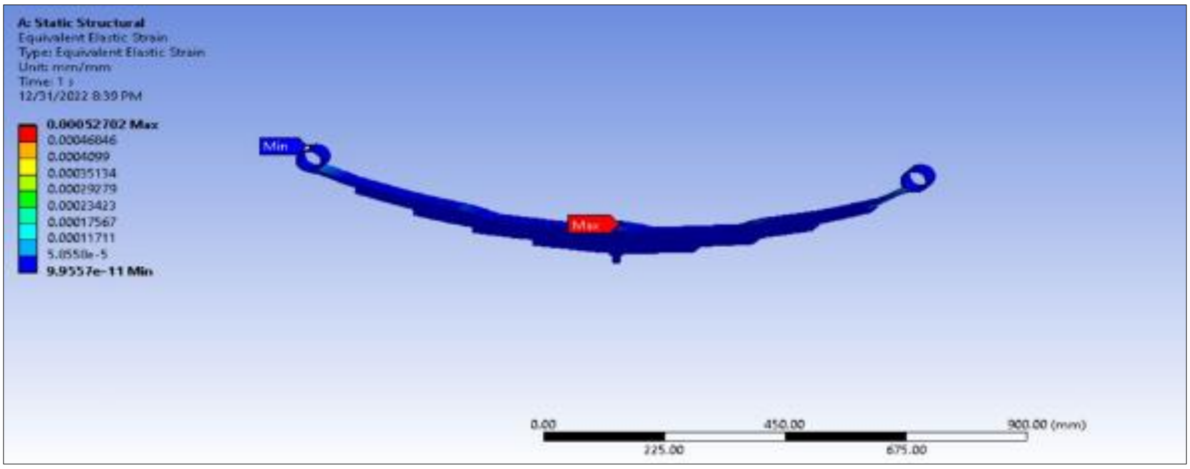

Figure 8 Chromium vanadium steel Model

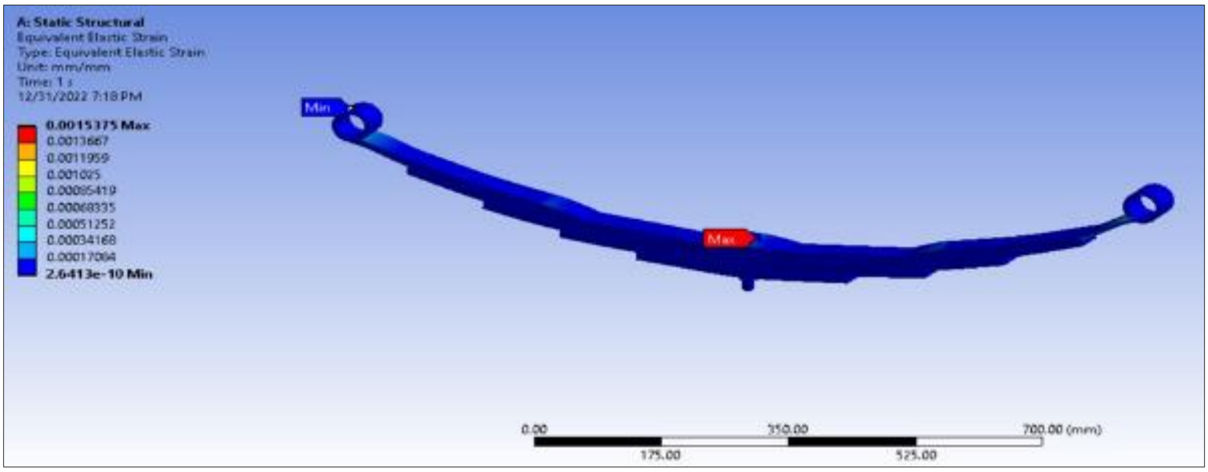

Figure 9 Aluminum 7075-T6 Model

3.3. Equivalent Von-Mises Stress of leaf springs

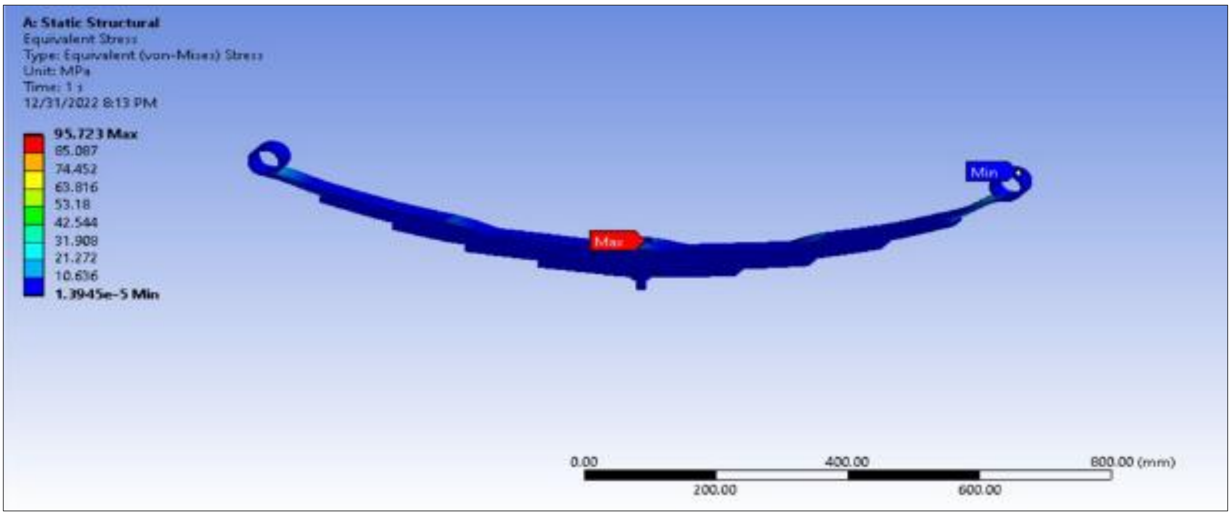

Figure 10 Plain carbon steel Model

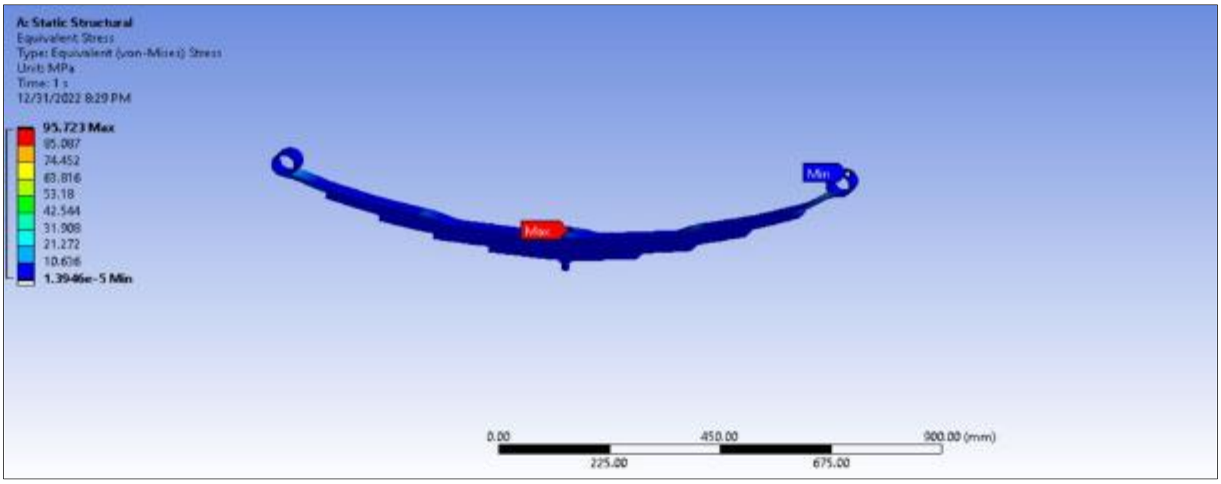

Figure 11 Chromium vanadium steel Model

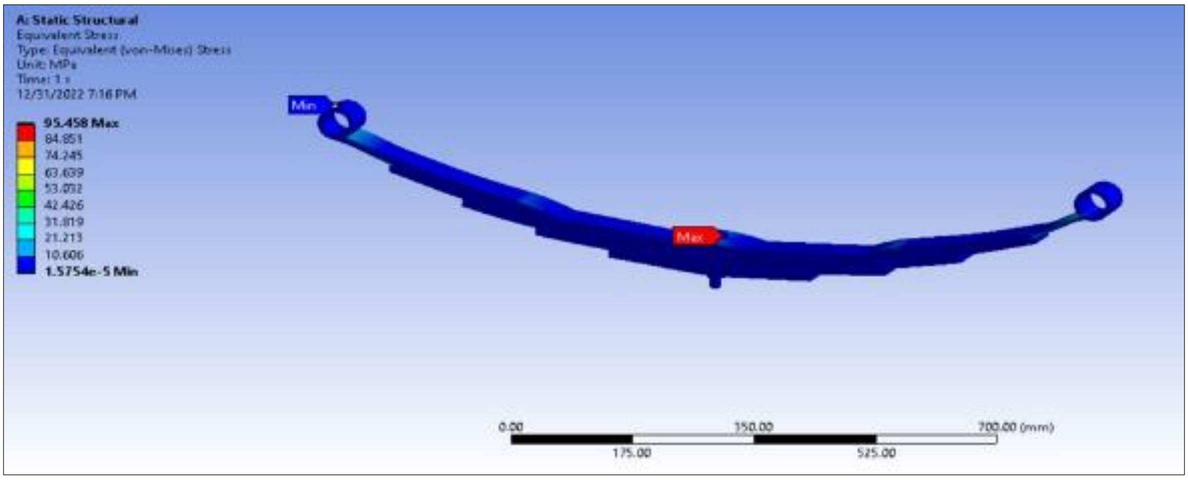

Figure 12 Aluminum 7075 -T6 Model

3.4. Maximum Shear Stress of leaf springs

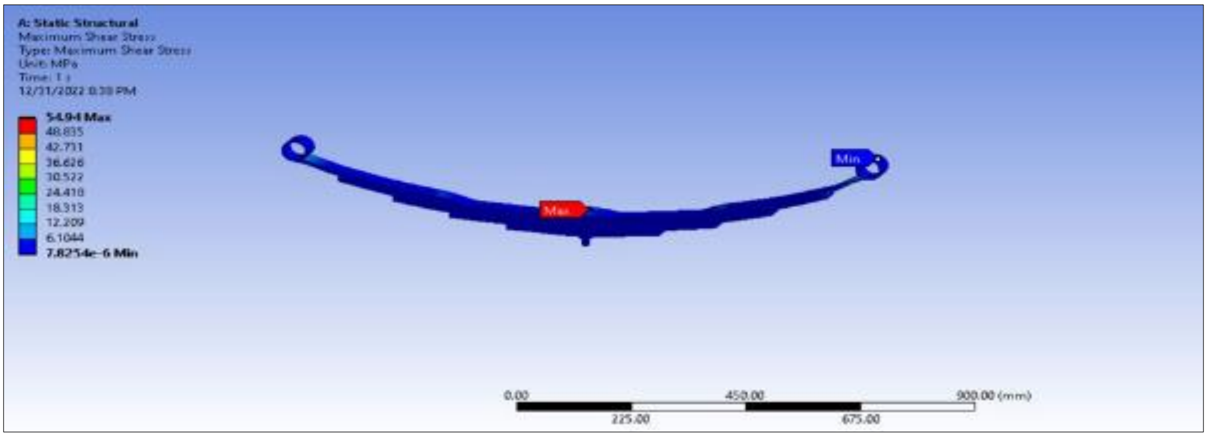

Figure 13 Plain carbon steel Model

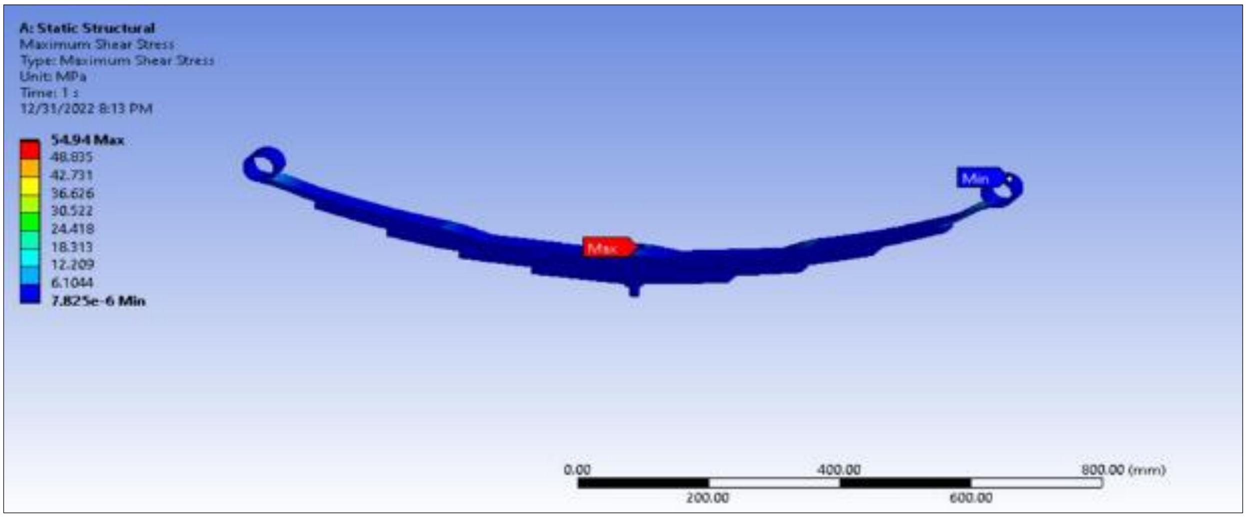

Figure 14 Chromium vanadium steel Model

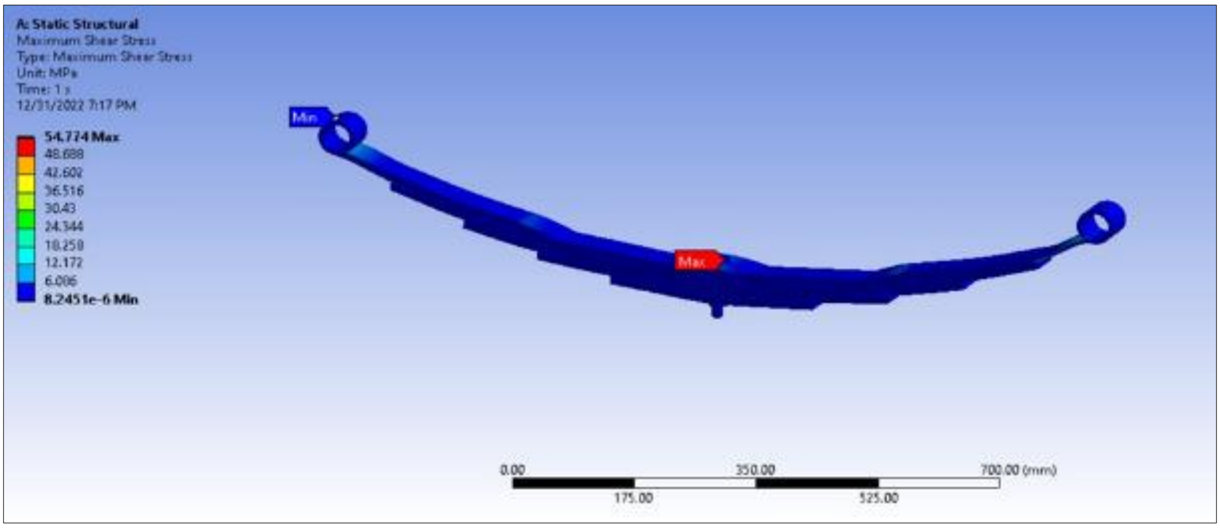

Figure 15 Aluminum 7075 -T6 Model

4. Discussion

4.1. Total Deformation

Deformations refer to the change of shape or size of a material when subjected to external force, load, or temperature. Figures 4, 5, and 6 show the total deformation results of the static structural analysis of the suspension leaf springs made of plain carbon steel, chromium-vanadium steel, and aluminum 7075-T6. Figure 16 shows a comparison of the total deformation of the plain carbon steel suspension leaf spring with 79.84%, chromium-vanadium steel suspension leaf spring with 15.13%, and aluminum 7075-T6 suspension leaf spring with 15.03%. The total deformations of the materials models all yielded different values but the aluminum 7075-T6 model was observed to be the lowest of 15.03%.

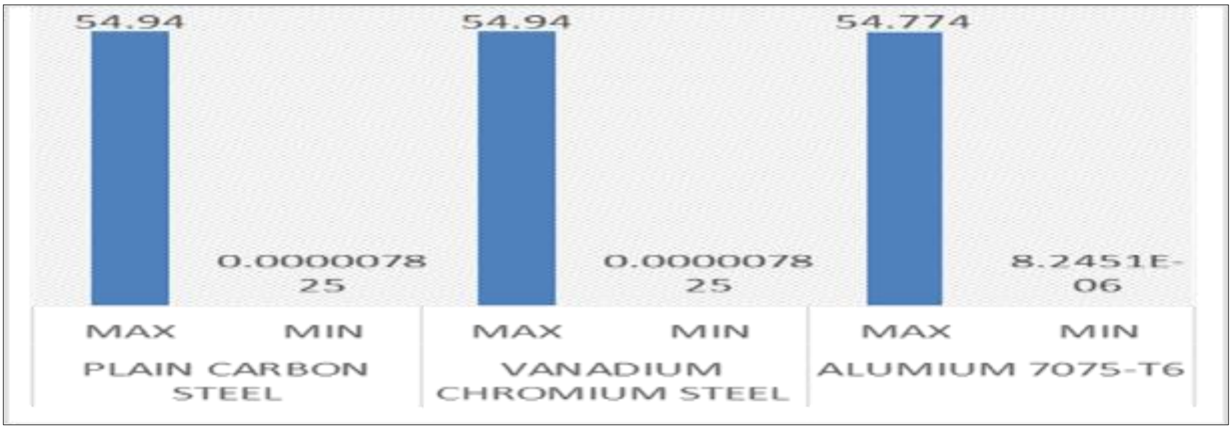

Figure 16 Comparison of Total Deformations Results

4.2. Equivalent Elastic Strains

Figures 7, 8, and 9 show the static structural analysis of the suspension leaf springs made of plain carbon steel, chromium-vanadium steel, and aluminum 7075-T6.

The equivalent elastic strain was used to measure the extent of deformation or the impact made by the deformation on the components. When the results were compared, it was observed that plain carbon steel suspension leaf spring suffered an equivalent elastic strain of 79.88%, Chromium vanadium steel suspension leaf spring suffered an equivalent elastic strain of 2.50%, and aluminum 7075-T6 suspension leaf spring suffered an equivalent elastic strain of 14.98% as shown in Figure 17.

These show that chromium-vanadium suspension leaf springs suffered the least equivalent elastic strain. The difference in percentage terms between chromium-vanadium steel is about 12.48% which is woefully insignificant to bring any changes between the equivalent elastic strains of the suspension leaf spring made of these two materials.

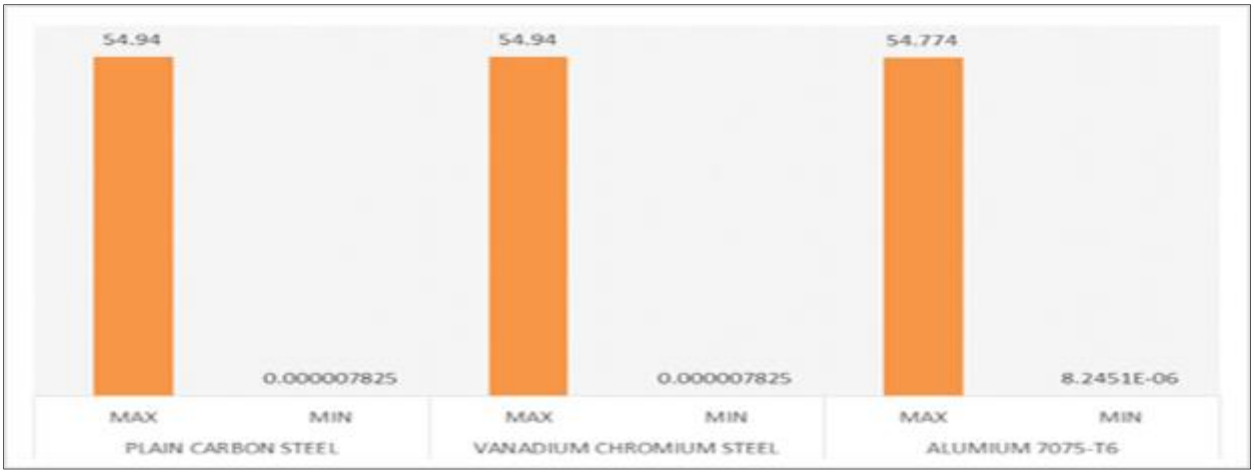

Figure 17 Comparison of Equivalent Elastic Strains Results

4.3. Equivalent Von Mises Stress

Figures 10, 11, and 12 present the static structural analysis of the suspension leaf springs made of plain carbon steel, chromium-vanadium steel, and aluminum 7075-T6.

One of the most significant parameters for this study is the Von Mises stress. This was used to determine whether the suspension leaf spring would fail or not when compared with the yield strengths of the materials. When the induced equivalent (Von Mises) stress is equal to 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. When the Von Mises stresses induced in the suspension leaf spring of the three different materials were compared as shown in Figure 18, the results show that the induced stress yielded in the plain carbon steel suspension leaf spring was, the chromium-vanadium steel suspension leaf spring yielded the same Von Mises stress percentage as the plain carbon steel whiles aluminum 7075-T6 suspension leaf spring yielded 33.27%.

Figure 18 Comparison of Equivalent von Mises Stresses Results

4.4. Maximum Shear Stress Results

Figures 13, 14, and 15 show the maximum shear stress induced in the suspension leaf springs. The results show that the plain carbon steel suspension leaf spring yielded a maximum shear stress of, the chromium-vanadium steel yielded the same percentage as plain carbon steel and the aluminum 7075-T6 yielded a maximum shear stress. It was observed that the suspension leaf spring made of plain carbon steel and chromium vanadium steel yielded the highest maximum induced shear stress while the suspension leaf spring made of aluminum 7075-T6 yielded the minimum shear stress. The comparison shows that aluminum 7075-T6 which is the implementing material in this study has superior properties to withstand shear stress than plain carbon steel and chromium vanadium steel.

5. Conclusion

The study has shown that aluminum 7075-T6 has superior properties to chromium-vanadium steel and plain carbon steel. The deformations suffered by the three materials suspension leaf springs were observed not to be significant enough to affect its smooth operation in practice, hence the suspension leaf springs made of plain carbon steel, chromium-vanadium steel, and aluminum 7075-T6 can be described to be fit for purpose.

This study therefore strongly recommends the use of aluminum 7075-T6 as a suitable material for the design and fabrication of suspension leaf springs and similar automobile components since it is very light and durable.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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