*Applied Mathematics, Modeling and Computer Simulation*
*C.-H. Chen et al. (Eds.)*


*doi:10.3233/ATDE231064*

# 3D Design of Helical Spring for Automotive Independent Suspension System Under Fatigue Test Conditions

Salah H. R. Ali[a, b, c, d,1], Mostafa Ahmed[d], Eslam Ehab[d], Youssef Taha[d], Ibrahim Samir[d] and Mina Sarwat[d]

[a]*Head of Mechatronics Engineering, Pyramids Higher Institute of Eng and Tech (PHI), 6th of October, Giza, Egypt*

[b]*Visiting Professor, Mechanical Engineering, Ahram Canadian University (ACU), 6th of October, Giza, Egypt*

[c]*Emeritus Professor, Precision Engineering Division, National Institute of Standard (NIS), Giza, Egypt*

[d]*Mechanical Engineering, Ahram Canadian University (ACU), 6th of October, Giza, Egypt*

**Abstract.** A helical spring is a critical part of an independent automobile suspension system. Helical coil-spring is subjected to stress as a result of tire excitation at contact with an uneven road surface. Design of helical spring is very vital in the light of many design parameters in order to improve passenger comfort and car stability on roads. In this paper the most important of parameters have been taken into consideration in the proposed 3D design such as type of spring material, geometrical dimensions and stresses. The proposed design of suspension spring aims to improve the kinetic energy storage capacity, expressed with deformation of the spring when tires are moving on the road surface in order to increase passenger comfort. This has been done to achieve a better safety factor while reducing the weight of a spring made of nanomaterials. In addition, comparisons have been made between the operation accuracy of the two common different FEA packages under fatigue test conditions. The results showed differences due to changing design parameters as well as the types of FEA software packages used.

**Keywords**: Auto suspension, spring design, nanomaterial, fatigue load and stability

## 1. Introduction

Automotive suspension system performs critical functions to ensure stability and comfortability for passengers in the event of dynamic vibrations resulting from road surface irregularities. Passenger cars have two types of suspension systems [1-2]. The first or oldest type called "Dependent suspension" includes leaf spring, which is common on the rear wheels, while the second type is called "Independent suspension" which is more comfortable for the passenger and safe for the car, so it is more common

[1] Corresponding Author, Salah H. R. Ali, *Head of Mechatronics Engineering, Pyramids Higher Institute of Eng and Tech (PHI), Giza, Egypt*; E-mail: salahali20@yahoo.com.

in the front of the car. Independent suspension systems in cars are considered a common type for superior performance, but they are somewhat complicated. This is especially important in the case of reaction for longitudinal acceleration, or deceleration during braking. The lateral forces generated when the car body turns in corners while driving right or left are also considered very crucial conditions. During the movement of the passenger car and with the undulations or irregularities of the road surface, the spring is exposed to high pressures, and then it rebounds to what may exceed its free length in the process of movement and ends with a balanced lift of the car body.

In movement on the road, the extended length exceeds the free length of the spring contraction and rebound with lower amplitude thanks to the damper (shock absorber). The up and down motion of the coil spring is then repeated until it is finally reduced in the form of decreasing sine waves. While if this way of bouncing occurs without any control, it causes an uncomfortable ride and makes the car difficult to stabilize. Therefore, interest is always in studying its vibrational behavior to find natural resonance frequencies that allow a better visualization of different dynamic conditions. The analysis of this type of element is complex due to the presence of bending, stretching, coupling, shear stress effects, and rotational inertia, in addition to the complexity of the shape of its structure [1-2]. There is a lot of research conducted in this field, but not all of them include the natural ends of the coil spring that are close to reality [3-10]. Therefore, in our new design we will plan to have a spring with a different geometric shape than the conventional one, with a completely different endpoint from previous research. This is in addition to the use of various other types of materials, including nanomaterials and studying safety standards. Accordingly, researchers are required to obtain the best spring design using Finite Element Analysis (FEA) techniques based on many factors of continuing importance to safety and occupant comfort. In addition, one of the goals of this work is to come up with a recommendation that serves students and researchers who want to obtain valuable results in design and analysis using computing programs.

## 2. Methodology

The working methodology will be as follows, the modified spring design to be tested using two FEA techniques (SolidWorks 2021 & Ansys R1 2021). Where the test will be divided into two parts, one is a static force test, and the other is a fatigue stress test in case infinite life. The two tests will run in the same surrounding conditions and influencing factors. The results will be compared in the next step. Design parameters of proposed helical spring indicates real geometrical dimensions were used in the simulation are presented in table 1. Table 2 illustrates the materials properties of the proposed three springs.

**Table 1**. Geometrical dimensions of proposed helical spring

| | | | |
|---|---|---|---|
| Free length ($L_f$) | 298.5 mm | Mean diameter for body coil ($D_m$) | 85, 101.5 mm |
| Solid length ($L_s$) | 148.5 mm | Spring index (C) | 5.814 |
| Outer diameter of base coil (D) | 55 mm | | |
| Outer diam. for body coil ($D_o$) | 93.25, 109.75 mm | Weight A | 3.293 Kg |
| Wire diameter (d) | 16.5 mm | Weight B | 3.316 Kg |
| Number of coils (n) | 9 | Weight C | 3.619 Kg |

**Table 2**. Materials properties of the proposed design of springs

| Material designation | A | B | C |
|---|---|---|---|
| Elastic modulus (MPa) | 208000 | 212000 | 190000 |
| Poisson's ratio | 0.35 | 0.25 | 0.29 |
| Shear modulus (MPa) | 77030 | 84800 | 72000 |
| Mass density ($kg/m^3$) | 7100 | 7150 | 7805.7 |
| Tensile strength (MPa) | 2680 | 2810 | 2450 |
| Yield strength (MPa) (0.75× Tensile Strength) | 2010 | 2107.5 | 2050 |

Three distinct materials, denoted as A, B, and C were subjected to testing on a 3D model to ascertain their relative performance in order to find out which one is better at the follows:

Three distinct materials, designated A, B, and C, were tested on a 3D model to ascertain their relative performance in order to see which one was better given the following assumptions:

- In the context of automotive applications, achieving optimal performance, comfort, and safety necessitates the specification of a low damping coefficient for the vehicle's body. It is imperative that the damping coefficient does not surpass the critical threshold (D=0.5) to ensure safety and comfort. Ideally, a body damping coefficient falling within the range of 0.25 to 0.35 represents an optimal compromise [11].
- In order to know the incoming impact to the spring through the movement of the car, loads aren't distributed equally on the spring, but there are other parts that absorb part of it and there the dumber is reduced from it as well, and for the difficulty of determining a specific value for it, a force will be assumed that it is a pure force that affects the spring.
- Putting in concern that the force acting on the spring in fatigue load test varies as a value with time and complexity of the outcomes, it was assumed that it is constant as a value and is repeated 1E+07 (10,000,000) cycles.

## 3. Simulation using Two FEA Techniques

Through simulation of automotive suspension coil spring, it will use two systems here, to obtain the advantages of both in the proposed design as follows:

### *3.1 Simulation using SolidWorks Technique*

In the static load test, a constant force of 7000 N is applied, while in the fatigue load test, a fluctuating force of 1000 N is applied for 10,000,000 cycles (representing an infinite life scenario) . In this context, the term "fixed support" signifies that the lower plate is rigidly secured in place, preventing its movement. Conversely, "applied force" refers to the external load or pressure exerted on the top plate, which can induce deformation or displacement in the system. To replicate the spring simulation will initiate a meshing process, number of nodes and elements are generated on the geometries were presented in table3.

**Table 3**. Number of nodes and elements generated on the geometries

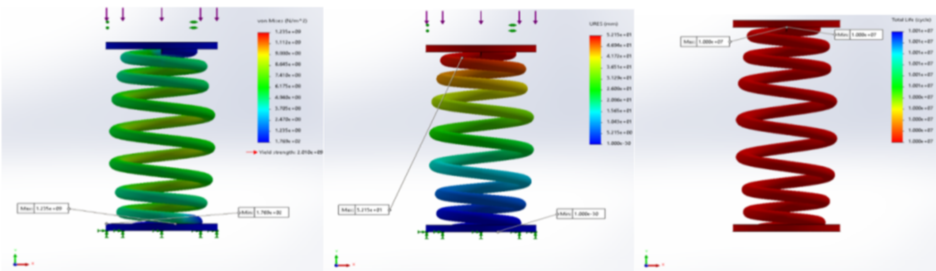
| | |
|---|---|
| Max element size | 3.72819mm |
| Min element size | 1.24272mm |
| Total elements | 103727 |
| Total nodes | 164119 |

### *3.1.1 Static load test*

In this exceptional part, a static load test will be performed using SolidWorks technique based on two theories as follows:

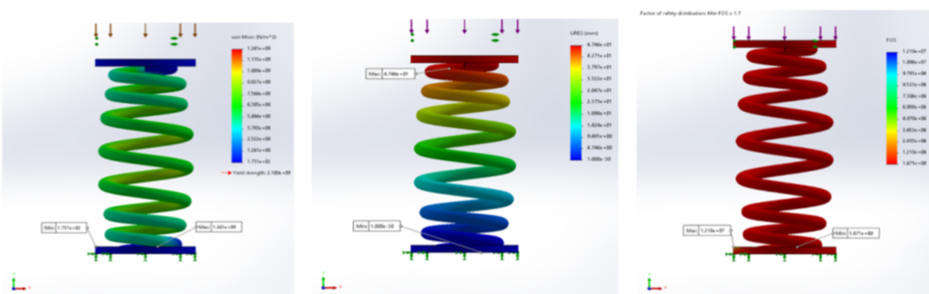
- Stress analysis calculated based on Max Von Mises theory.
- The factor of safety (FoS) is calculated based on Soderberg theory (yield strength).

Figure 1 presents stress results, deformations, and safety factors for material A, offering valuable insights into its performance and safety characteristics a follows. While, a) Equivalent Von Mises stress is a measure of the combined effect of all stress components in the material, providing a comprehensive stress assessment. (b) Total deformation quantifies the overall displacement or distortion experienced by the material or structure under the applied load. (c) Factor of safety is a crucial metric that assesses the safety margin in a design by comparing the material's actual stress to its allowable stress. Figure 2 provides insights into stress results, deformations, and safety factors for material B, aiding in the assessment of its performance and safety characteristics. Figure 3 presents stress results, compressibility data, and safety factors specific to material C, offering valuable information for evaluating its performance and safety aspects.



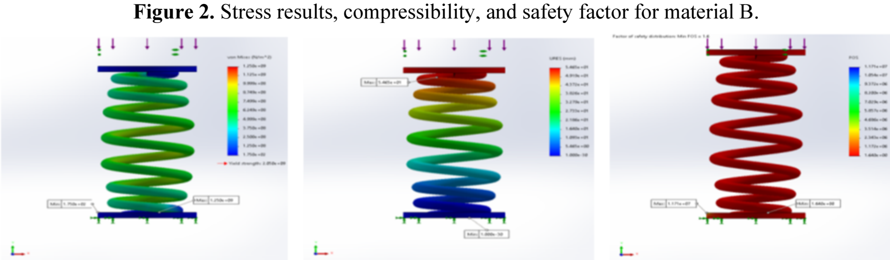
a. Equivalent Von Mises b. Total deformation c. Factor of safety

**Figure 1.** Stress results, compressibility, and safety factor for material A.



a. Equivalent Von Mises b. Total deformation c. Factor of safety

**Figure 2.** Stress results, compressibility, and safety factor for material B.



a. Equivalent Von Mises b. Total deformation c. Factor of safety

**Figure 3.** Stress results, compressibility, and safety factor for material C.

### *3.1.2 Fatigue load test (infinite life)*

Fluctuating force of 1000N is applied in fatigue load test at 1E+07 cycles (infinite life). The S-N curve driven from material modulus of elasticity based on ASME Austenitic steel curves on both programs. FoS was calculated based on Soderberg stress theory. This data helps assess the endurance and safety characteristics of these materials under cyclic loading conditions, see table 4.

**Table 4.** Fatigue results

| Material | FoS | LIFE |
|---|---|---|
| A | 1.041 | 1.0e+07 Cycle |
| B | 1.033 | |
| C | 0.9352 | |

### *3.2 Simulation using ANSYS Technique*

Fixed geometries are same fixtures and force was applied on **ANSYS**. The resulting in table5 displays the number of nodes and elements generated within the geometries at the specific conditions as follow:

- In the static load test, a force of 7000 N is applied.
- In the fatigue load test, a force of 1000 N is applied, and the test is conducted for 10,000,000 cycles, representing an infinite life scenario.
- Stress analysis is performed using the Max Von Mises theory.
- FoS is calculated based on the Soderberg theory, considering the yield strength of the material.

**Table 5.** Number of nodes and elements generated on the geometries

| | |
|---|---|
| Total nodes | 19284 |
| Total elements | 10567 |
| Max element size | 37.337 mm |
| Curvature min size | 0.18669 mm |

### *3.2.1 Static load test*

Table 6 presents stress results, deformations, and safety factors for material A, offering valuable insights into its performance and safety characteristics. Table 7 presents stress results, compressibility data, and safety factors specific to material B, offering essential information for assessing its performance and safety attributes. Table 8 displays stress results, compressibility information, and safety factors specific to material C, providing valuable insights into its performance and safety characteristics.

**Table 6.** Static load results

| | |
|---|---|
| Max Von Mises stress | 1311.2 MPa |
| Min Von Mises stress | 3.3339e-04 MPa |
| Displacement | 54.526 mm |
| Spring stiffness (Calculated using [12-13]) | 128.379 $N/mm^2$ |
| FoS | 1.5329 |

**Table 7.** Static load results

| | |
|---|---|
| Max Von Mises stress | 1247.9 MPa |
| Min Von Mises stress | 3.1869e-04 MPa |
| Displacement | 49.596 mm |
| Spring stiffness (Calculated using [12-13]) | 141.140 $N/mm^2$ |
| FoS | 1.6893 |

**Table 8.** Static load results

| | |
|---|---|
| Max Von Mises stress | 1272.8 MPa |
| Min Von Mises stress | 3.2786e-04 MPa |
| Displacement | 57.081 mm |
| Spring stiffness (Calculated using [12-13]) | 122.633 $N/mm^2$ |
| FoS | 1.6107 |

**Table 9.** Fatigue results

| Materials | FoS | Cycles |
|---|---|---|
| A | 1.1104 | 1.0e+07 Cycle |
| B | 1.1892 | |
| C | 1.045 | |

**Table 10.** Compression between results of two FEA techniques

| Parameters | Using SoldWorks FEA technique | | | Using ANSYS FEA technique | | |
|---|---|---|---|---|---|---|
| Static axial load, N | 7000 | | | | | |
| Environment temperature, ºC | 22 | | | | | |
| Material used | A | B | C | A | B | C |
| Max Von Mises stress, MPa | 1235 | 1261 | 1250 | 1311.2 | 1249.9 | 1272.8 |
| Total deformation, mm | 52.15 | 47.46 | 54.65 | 54.526 | 49.596 | 57.081 |
| FoS | 1.628 | 1.671 | 1.64 | 1.5329 | 1.6893 | 1.6107 |
| Fatigue axial load, N | 1000 | | | | | |
| Number of Cycles | 1E+07 Cycle | | | | | |
| Fatigue Life | 1E+06 Cycle | | | | | |
| FoS | 1.041 | 1.033 | 0.9352 | 1.1104 | 1.1892 | 1.045 |

### *3.2.2 Fatigue load test (infinite life)*

Table 9 presents the life results and safety factors for three materials, A, B, and C, obtained from a fatigue test. This data helps evaluate the endurance and safety characteristics of these materials under cyclic loading conditions.

## 4. Comparisons and Analyses

A finer mesh contributes to a more precise representation of the 3D model, which can result in variations in meshing values between the two scenarios. Consequently, discrepancies in the results emerged after conducting both the constant and variable stress tests. Table 10 presented here summarizes the outcomes for all three materials, elucidates the disparities among them, and delineates the test conditions for each. Despite variations in the methodologies employed by each program within the solution, it's noteworthy that the discrepancies remain relatively minimal, see table10.

### *4.1 Applied simulations*

The simulations of the models were conducted using both programs for the three different materials as follows. Deformation results of selected materials using SolidWorks technique were presented in Fig.4. Deformation results of selected materials using ANSYS technique were presented in Fig.5. The Figs 4-5illustrate the correlation between two variables: force and deformation. The design underwent testing across a range of force values, spanning from 1000 N to 10000 N, incrementing by 1000 N at each step. These tests encompassed all three materials, and the resulting deformations were recorded. Notably, Material B exhibited the lowest deformation value at 103 mm (representing 34.3% of the maximum deformation), whereas Material C exhibited the highest deformation value at 118.7 mm (equivalent to 39.67% of the maximum deformation).

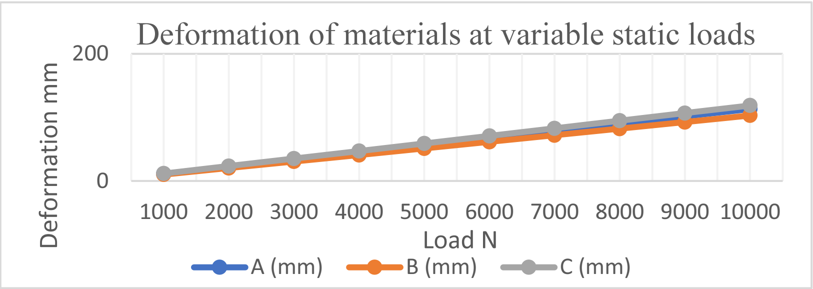



**Figure 4.** Load induced deformation for different materials using SolidWorks

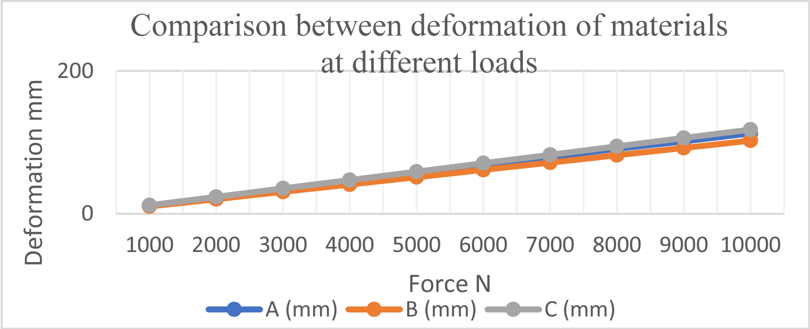



**Figure 5.** Load induced deformation for different materials using ANSYS

Figure 6-9 was generated based on two distinct simulations. It is important to note that the applied load remained constant at 7000 N, and the wire diameter was systematically varied within the range of 10 mm to 20 mm, increasing by 1 mm increments. So, the effects of wire diameter results on deformation for selected three materials using SolidWorks technique were presented in Fig.6. The effects of wire diameter results on FoS for selected three materials using SolidWorks technique were presented in Fig.7. The effects of wire diameter results on deformation for selected materials using ANSYS technique were presented in Fig.8. The effects of wire diameter results on FoS for selected materials using ANSYS technique were presented in figure 9.

In figure 6 and 8 using both software techniques, material B demonstrated the lowest deformation value while material C showcased the highest deformation value. In Fig7 and 9 using both software techniques, material B exhibited the highest factor of safety value whereas material A displayed the lowest factor of safety.

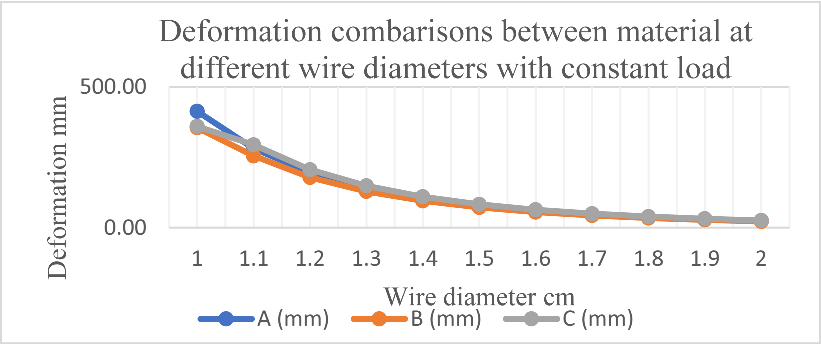



**Figure 6.** Wire diameter induced deformation for different materials using SolidWorks

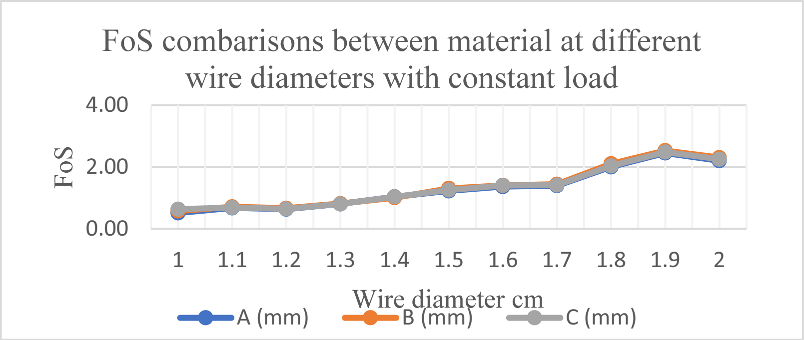



**Figure 7.** Wire diameter induced FoS for different materials using SolidWorks

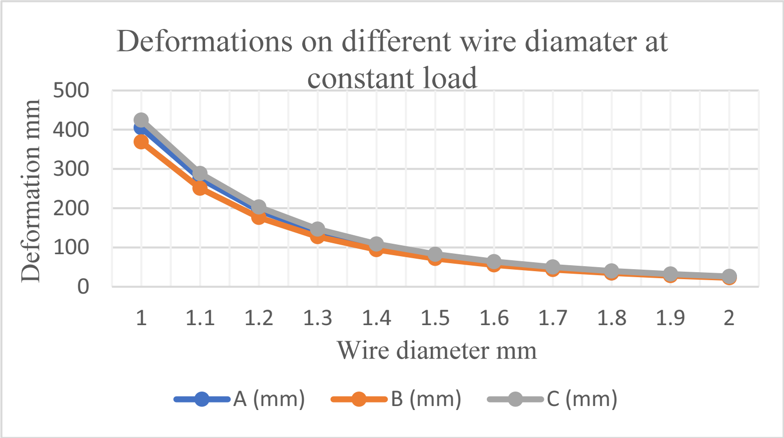



**Figure 8.** Wire diameter induced deformation for different materials using ANSYS

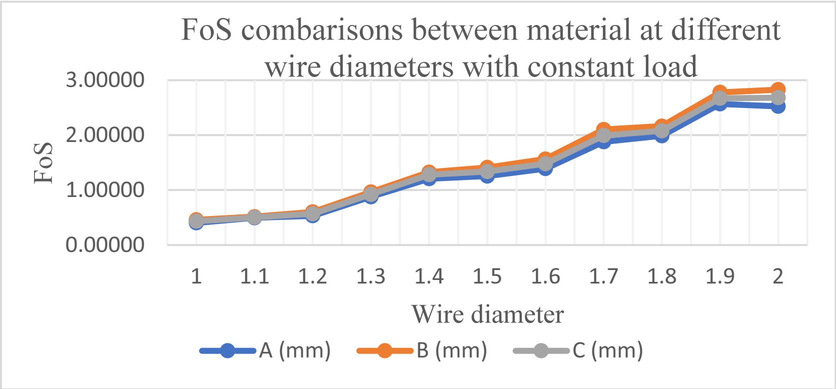



**Figure 9.** Wire diameter induced FoS for different materials using ANSYS

## 5. Conclusions

In this paper, several parameters are taken into consideration in the 3D design of the helical spring of an automobile independent suspension system under fatigue test conditions. The proposed spring was designed at different types of materials, geometric dimensions and stresses. This is to achieve the best spring with the largest kinetic energy storage capacity, which is expressed by spring deformation, in order to increase passenger comfort. The safety factors were also verified to test the best way to reduce the weight of the spring made of nanomaterials. In addition, comparisons were made between the machining accuracy of two different common FEA packages under fatigue test at certain conditions. The conclusion can be summarized as follows:

- The spring design, optimized for independent suspension of passenger cars, was successfully validated. From the interpretation of the results of using three proposed materials in the design as well as the software platforms: you notice that the results were different for the same design factors, so it is certain that there is a clear difference in the methodology of computing these programs. However, it is important to note that these differences were not very significant. However, when we take into account the different variety of materials used, the differences become more apparent.
- Material B showed a high response to stress and the safety factor was most appropriate, while Material A showed the lowest safety factor. Meanwhile, material C was highly sensitive to stresses, with significant length shrinkage of 19%.
- Material B has been shown to be a superior option in terms of safety and reliability factors, primarily due to its ability to withstand higher tensile stresses than A and C, as well as yield stress values.
- Material C revealed that the safety factor result when using SolidWorks software was less than the acceptable limit, although it was slightly higher when using another software. Therefore, the use of this substance may pose a safety risk.
- Regarding spring weight considerations, Material A showed great distinction as the most lightweight option among the three materials selected.
- Furthermore, results indicate that ANSYS software consistently demonstrated greater accuracy under the specific working conditions of the study subject.

Eventually, the curriculum confirmed that using the SOLIDWORKS program is distinctive in creating three-dimensional models and using the ANSYS program is distinctive in simulating engineering problems.

**Acknowledgment**: We, the second, third, fourth and fifth authors, extend our sincere thanks, appreciation and gratitude to Professor Dr. Salah H.R. Ali (first author), because he taught us the subject “Mechanical Design” during a semester and was able to guide us to participate in the completion of this paper, so our efforts focused on running the program and the results. We also thank Al-Ahram Canadian University for selecting specialized professors to teach us and for participating in producing scientific research before graduation.

## References

[1] Fahd V. Hassan, Suspension System: Components, Types, and Working Principle, 2020. Website at: https://www.fahadhvhassan.com/suspension-system-components-types-and-working-principle/

[2] INGENIERIA Y MECANICA AUTOMOTRIZ, Suspension system: components, types and working principle, 26 Jul 2019.Website at: https://www.ingenieriaymecanicaautomotriz.com/suspension-system-components-types-and-working-principle/

[3] V.B. Bhandari, Design of Machine Elements" Book, Publisher: Tata McGraw-Hill, ISBN: 0070681791, 9780070681798, 2010.

[4] Ramakrishnan, K. K., & Ramakrishnan, S, Static and Dynamic Analysis of Helical Springs Using Finite Element Analysis, International Journal of Mechanical Engineering and Robotics Research, 3(4), 159-166, 2014.

[5] Bhawar, D. B., & Gawande, S. A., Design and Analysis of Helical Compression Spring Using Finite Element Analysis, International Journal of Engineering Research and General Science, 2(4), 146-152, 2014.

[6] Senthilkumar, K., & Arul, S., Design and Analysis of Helical Compression Spring by Finite Element Analysis, International Journal of Engineering Research and Technology, 4(9), 2293-2299, 2015.

[7] S. K. Gupta, and R. Shukla, Design and Analysis of Helical Compression Spring by Finite Element Method, International Journal of Scientific and Research Publications, 6(3), 116-120, 2016.

[8] Sharma, A., & Gupta, V. K., Analysis of Helical Compression Spring by Finite Element Analysis, International Journal for Research in Applied Science & Engineering Technology, 5(IV), 450-454, 2017.

[9] Singh Pankaj, Amilkanthwar Rushikesh, Walli Sanket, Jasoliya Viraj, and Patel Kaushal, Design and Analysis of Helical Compression Spring Used in Suspension System by Finite Element Analysis Method," Published in a journal with p-ISSN: 2395-0072 and e-ISSN: 2395-0056, 2017.

[10] Arvind Katyayn, Chitta Ranjan Tripathy, Design and Analysis of Helical Coil Spring to Improve Its Strength Through Geometrical Modification, Paper ID: IJTRS-V5-I4-034, 2020.

[11] Howard E. Boyer, Atlas of Fatigue Curves, Book, Publisher: ASM Intl, ISBN: 0871702142, 9780871702142, 1986.

[12] Richard Budynas and Keith Nisbett, Shigley's Mechanical Engineering Design, Book, 9th Edition, McGraw-Hill, ISBN: 0073529281, 9780073529288, 2010.

[13] John L. Porteiro, Spring Design Optimization with Fatigue, PhD thesis, University of South Florida, April 1 2010.