STM JOURNALS

Journal of
Polymer & Composites

https://journals.stmjournals.com/jopc

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 2, 2026
DOI (Journal): 10.37591/JoPC

Research JoPC

Enhancement of the Life of Helical Spring Systems

Annapureddy Bala Yaswanth Sai Reddy[1,*], G. Diwakar[2]

Abstract

Helical springs are essential mechanical factors considerably employed in automotive, aerospace, and artificial systems because of their capability to store and release energy, absorb shock, and sustain repeated weight cycles. The performance, responsibility, and durability of these springs play a vital part in ensuring the effectiveness and safety of the entire system in which they are integrated. Over time, numerous researchers have focused on strategies to enhance the service life of helical springs, as these factors are constantly subjected to fatigue failure under continuous cyclic loading. Literature reports indicate that factors analogous to material selection, face modification, and geometric optimisation significantly impact the fatigue resistance and overall continuance of springs. In this study, an attempt has been made to compare the life of helical springs manufactured from a conventional pristine brand and a pristine brand coated with Nickel–Phosphorus (Ni–P) and Silicon Carbide (SiC) emulsion coating. The coating is anticipated to conduct superior hardness, wear resistance, and corrosion protection, thereby extending service life. A detailed review of the former disquisition was conducted to establish the effectiveness of analogous approaches. Likewise, ANSYS simulation software was employed to model and analyse the springs under realistic loading conditions, and the results validated advancements reported in the literature.

Keywords: Helical springs, fatigue life, stainless steel, nickel – phosphorus (Ni – P), silicon carbide (SiC) conflation coating, ANSYS simulation

INTRODUCTION

An effective mechanical tool for storing and releasing energy is a spring. Depending on the needs of the application, springs can be produced in a variety of shapes, including a flat wound-up strip, a stamped piece, or a helical coil of wire. The most widely used kind of these is the helical compression spring, which is included in practically every mechanical product [1].

Helical springs are fundamental mechanical components with a spiral form created by winding a wire around a central axis. Based on their construction and application, they can be categorized into three primary types: compression springs, which counteract forces that compress them and shorten in response to loading; tension or extension springs, which resist forces that stretch them and elongate when pulled; and torsion springs, which oppose twisting or rotational forces.

However, using a hollow circular shape for the cross-section can greatly reduce the weight of the spring. Due to this benefit, many researchers have investigated the development of hollow helical springs for use in engineering applications. The main goal of these studies is to design a spring that meets specific requirements and design guidelines. One of the main difficulties in this process is making sure that the newly designed hollow helical spring follows all applicable technical standards while still performing well [2].

***Author for Correspondence**
Annapureddy Bala Yaswanth Sai Reddy

[1]M. Tech Student, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India
[2]Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India

Received Date: September 16, 2025
Accepted Date: December 16, 2025
Published Date: March 26, 2026

Citation: Annapureddy Bala Yaswanth Sai Reddy, G. Diwakar. Enhancement of the Life of Helical Spring Systems. Journal of Polymer & Composites. 2026; 14(Special Issue 2): S12–S24p.

Recent research demonstrates the potential of hollow helical springs to dramatically reduce weight without compromising performance. Bagaria et al. developed nomograms—graphical tools based on established formulas—to simplify the design of hollow helical suspension springs, showing that such springs can yield weight reductions of around 50 % or more compared to conventional solid-wire springs. Additionally, hollow springs can serve dual purposes, such as enabling heating or cooling fluids to circulate through them, beneficial in extreme temperature environments [3].

Beyond material form, design optimization techniques offer powerful strategies for enhancing spring performance. For instance, in the International Journal of Advanced Science and Technology, Rahul et al. tackled a bi-objective optimization for helical coil springs: minimizing spring volume (and thus cost and mass) while maximizing strain energy. They employed a Non-Dominated Sorting Genetic Algorithm II (NSGA-II) to generate Pareto-optimal design solutions, which were then validated numerically [4].

In addition, composite helical springs are becoming increasingly attractive options. A review published in Composite Structures notes that polymer matrix composite helical springs (PMCHSs) can achieve up to 34.4% less weight compared to metal springs while keeping the same spring constant; with additional optimization, the weight reduction compared to non-optimized PMCHSs can reach 8.3% [5].

In another study, the researchers constructed nomograms which designers can use to quickly chart a few important nondimensional functions of hollow-wire helical springs such as hollow wire size and coil diameter. They demonstrated for such geometries, that to achieve the same level of stiffness and strength, their hollow coil geometry enabled a >50% weight reduction with respect to solid-wire. This result confirms the previous observation that hollow circular sections are very efficient in lightweight spring design [6]. Another work has studied polymer-matrix composites as helical springs. The unidirectional, multistrand and wrapped textile-reinforced fibers were constructed by the researchers, and it was witnessed that the latter showed a significant enhanced performance in compression strength. With a ductility-enhanced spring constant the composite spring mass might be reduced to 75 %, 63 % and 49 % of that of steel springs respectively. These findings demonstrate that by using advanced materials in combination with optimized geometries it is possible to reduce weight consumption while still preserving mechanical performance [7].

Another overview also shows the more general research direction of spring technology: hollow helical springs, composite springs as well as optimization techniques (it can be analytical, numerical, and even experimental) are becoming all together a reliable way for minimizing mass of spring so that fatigue life, strength and stiffness requirements to spring can also be satisfied. The authors also report that the potential use of this hollow-spring concept in weight reduction, design flexibility are attractive, but the manufacturing complexity and the cyclic durability needs to be investigated [8].

MATERIAL SELECTION

Material taken: Stainless Steel

Stainless steel is an iron-based alloy known for its strong resistance to corrosion and staining. The development of this material is traced back to experiments conducted in the early 1800s, leading to its commercial production in 1913 by Harry Brearley. Stainless steel is classified into several main types—namely, austenitic, ferritic, martensitic, duplex, and precipitation-hardening—based on their structural features, physical properties, and applications.

Over time, stainless steel has been developed into different types based on their metal structure—ferritic, austenitic, martensitic, duplex, and precipitation-hardening. Each type has its own structural features and performance qualities that make it suitable for different uses. This metal is widely used in many areas such as construction, food processing, medical tools, cars, airplanes, and chemical plants because it is strong and can resist corrosion. In 2020, the world produced about 52.2 million tons of stainless steel, showing how important it is for modern industries and daily life. Scientists are still working to improve stainless steel by changing its composition and production methods, so it can work better in more situations while staying affordable and easy to use [9].

Stainless steel comes in various types, such as austenitic, ferritic, martensitic, duplex, and precipitation-hardening, each designed for specific uses due to their distinct characteristics. Because of its strength, ability to withstand heat and corrosion, stainless steel is commonly used in many industries, including construction, medical equipment, food processing, and kitchen tools.

- Corrosion resistance: The chromium present in stainless steel creates a protective oxide layer on its surface, which helps prevent rust and corrosion.
- Strength and durability: Stainless steel has high mechanical strength and is very durable, making it suitable for long-term use in various environments.
- Ease of cleaning and maintenance: The smooth surface of stainless steel makes it simple to clean and maintain, which is why it is often chosen for applications where cleanliness is important.
- Versatility: Stainless steel is easy to shape and work with, allowing for a broad range of designs and uses.

Composite Materials:

Composite materials are used in various areas of human society, including the construction industry for structures like buildings and bridges, the automotive sector for components such as car bodies, the aerospace field where materials with high strength and low weight are needed, the production of home and industrial items such as storage tanks, bathtubs, sinks, and shower stalls, and the medical field as biomaterials for tissue repair and replacement [10].

These materials have become widely recognised because they combine the best features of two or more different materials, leading to better performance than traditional materials. Their high strength-to-weight ratio, resistance to corrosion, stability under heat, and adaptability in design make them essential in modern engineering. Also, progress in polymer, ceramic, and metal-based composites has allowed the creation of materials suited for particular purposes, such as resistance to wear, endurance under repeated stress, and compatibility with the human body. As research and innovation continue, composites are playing an increasingly important role in sustainable technologies, lightweight designs, and advanced medical solutions.

Automotive applications A literature review on automotive applications reveals that composite materials, particularly the fibre reinforced polymers, have been increasingly used in the manufacture of vehicles, owing to their lightweight and strength properties. These materials result in lower structural mass and consequently improved fuel economy and reduced emissions, yet provide necessary stiffness and injury protection for the occupants [11]. In the aerospace sector, a recent review points out that composite materials like carbon-fibre-reinforced polymers and metal-matrix and ceramic-matrix composites are being employed more often than ever in the construction of aircraft because of their superior strength-to-weight ratios, high resistance to corrosion and fatigue. These advancements enable longer life, greater payloads and lower cost of operations in airframes and engines [12].

Reasons for selecting composite materials

Unlike materials such as steel, which have consistent and fixed properties, composites can be tailored to have varying characteristics. A shared characteristic among most composite materials is their favorable weight-to-strength ratio, which contributes to their wide application across various sectors such as biomedical, automotive, and aerospace. These materials are generally designed to meet specific requirements in terms of strength and performance, often surpassing the capabilities of alternative materials.

Such material properties include

- High corrosion resistance
- High fatigue resistance
- High impact strength
- Low weight-to-strength ratio
- Low thermal and electrical conductivity
- High wear resistance
- Creep resistant

Nickel–Phosphorus (Ni–P) + Silicon Carbide (SiC) composite coating

Nickel–phosphorus (Ni–P) coatings reinforced with silicon carbide (SiC) particles are a widely studied class of wear- and corrosion-resistant composite coatings in which a hard ceramic phase (SiC) is co-deposited into a ductile, protective Ni–P matrix. Electroless (chemical) and electrodeposition routes both enable uniform incorporation of SiC into Ni–P or Ni layers, producing a composite that combines the corrosion resistance and conformity of Ni–P with the high hardness and abrasion resistance of SiC [13].

The common motivation reported across experimental studies is performance enhancement: adding SiC raises microhardness, lowers friction and wear rates, and—when well dispersed—can improve tribological lifetime without greatly sacrificing the corrosion-protective behaviour of the Ni–P matrix. However, the property gains depend strongly on particle size, loading, and dispersion; even small loadings of well-dispersed SiC nanoparticles can produce measurable improvements in hardness and corrosion resistance [14].

Likewise, heat-treatment or post-processing (including thermal or laser treatment) is frequently used to convert amorphous Ni–P into crystalline Ni + Ni_3P phases, which raises hardness further but can change corrosion behaviour—so heat-treatment schedules must be optimised for the intended service environment [15]. Typical applications reported in the literature include automotive components (piston rings, sliding parts), bearings, and any components exposed to combined wear and corrosive environments where improved surface hardness and reduced wear are needed while maintaining corrosion protection. The combined literature therefore frames Ni–P/SiC as a flexible, tunable coating system: performance improvements are repeatable but require careful control of particle dispersion, bath chemistry, deposition parameters, and post-deposition heat treatment.

It was found that the grain size of the nickel phase decreased and the coating became denser when ceramic SiC particles were dispersed into the Ni–P matrix, leading to improved hardness and corrosion resistance. For instance, the grain size of electrodeposited Ni–SiC composite coatings decreased with increasing SiC loading and a minimum corrosion current density was obtained when its microstructure was in the most compact representation, suggesting that particle distribution influences barrier behavior coarsely [16].

The phase structure of Ni–P/SiC coatings also changes, following heat-treatment: the initial amorphous state is transformed to give crystalline Ni + Ni_3P and (in the presence of SiC) maximum hardness from heating at lower temperatures. Nonetheless, despite the gain in hardness, wear tests often reveal that the SiC-reinforced coatings have, on occasion, higher friction coefficients (due to third-body abrasion from particles) unless the heat-treatment schedule is carefully crafted, highlighting the competing action of reinforcement + thermal processing [17].

Material Properties

The material properties of stainless steel and Ni–P + SiC-coated stainless steel are presented in Table 1.

Table 1. Material properties

Property	**Stainless Steel**	**Stainless Steel coated with Ni-P + Sic composite**
Hardness	~150–250 HV	600–1200 HV
Wear Resistance	Moderate	Very high, due to hard SiC reinforcement and Ni–P matrix
Corrosion Resistance	Excellent in many environments	Enhanced further, especially in acidic/alkaline solutions, because Ni–P adds barrier protection
Friction Coefficient	~0.5–0.6	~0.2–0.3
Surface Roughness (Ra)	Moderate (machined ~0.2–0.6 µm)	Reduced
Fatigue Resistance	Good but decreases under corrosive environments	Improved due to load-bearing capacity of SiC and protective Ni–P layer
Coating Thickness	(substrate only)	10–50 µm
Service Life	Limited in high-wear/corrosive environments	Significantly extended due to wear + corrosion resistance synergy

DESIGN OF THE HELICAL SPRING

Helical springs are ubiquitous elastic elements that store and release energy under axial, torsional, or bending loads in mechanisms ranging from vehicle suspensions to precision devices. Their design starts with selecting spring type (compression, extension, torsion) and defining geometric variables: wire diameter (d), mean coil diameter (D), spring index (C = D/d), and number of active coils (Na) to achieve a target stiffness and deflection while respecting space and load constraints. Classical closed-form relations for shear stress, deflection, and spring rate—augmented by curvature and direct-shear corrections via the Wahl factor—remain the baseline for sizing and checking a design.

Beyond the simple, linear range where small deflections occur, real springs often show a nonlinear relationship between force and displacement. This is because of factors like coil contact, changes in pitch or diameter, and the nonlinear properties of the material. Recent studies have developed analytical and finite-element methods to account for these effects. These methods allow for the design of springs with complex shapes while still connecting to standard sizing parameters. This improves the accuracy of predictions for stiffness and stress under real-world conditions [18].

Fatigue performance is central to spring design because components typically operate under millions to billions of cycles. Studies in the very-high-cycle regime show how surface condition, inclusions, and residual stresses govern crack initiation and growth, and they highlight shot peening as a key treatment to introduce near-surface compressive residual stresses and raise endurance limits [19]. However, the beneficial residual stresses from peening can relax during service due to cyclic loading, surface roughness evolution, and geometry-specific effects (e.g., helix angle). Understanding—and designing against—this stress relaxation is vital for maintaining long-term fatigue resistance, informing choices on peening intensity, coverage, and post-treatments [20].

Modern spring design increasingly leverages optimisation under manufacturing and material variability, treating wire diameter, coil diameter, and coil count as decision variables under constraints such as stress limits, buckling, surging, and required stiffness. Robust algorithms can target minimum mass/volume or maximum reliability while accounting for tolerances and scatter in properties—bridging classical formulas with computational design for production-realistic springs [21].

MODELLING AND ANALYSIS:

4.1 Fusion 360: Fusion 360 is a unified design platform developed by Autodesk that integrates industrial design, structural design, mechanical simulation, and computer-aided manufacturing (CAM) into a single collaborative environment. It bridges traditional gaps between design and manufacturing by enabling seamless cross-platform workflows and cloud-based sharing. The software also supports cloud-enabled finite element analysis (FEA) and generative design, enhancing productivity and enabling reliability-driven design optimisation [22]. In my paper, two different springs were designed using Fusion 360, and the dimensions were kept identical for both models. The 3D model of the designed spring is shown in Figure 1.

The geometric dimensions used for both spring models are listed in Table 2.

Fusion 360 Model

The helical spring model was designed using Fusion 360 with predefined geometric parameters such as coil diameter, number of coils, and height. The software enables precise 3D modelling and provides a platform for integrating design with simulation. The model created represents a compression spring, which was later used for structural and fatigue analysis under specified loading conditions.

Analysis

The boundary conditions applied for static structural analysis are summarised in Table 3.

RESULTS AND DISCUSSION

From ANSYS Software, the results of the Structural Analysis and Fatigue Life Analysis using both materials, which are Stainless Steel and Stainless Steel with Nickel–Phosphorus (Ni–P) + Silicon Carbide (SiC) composite coating, are presented below.

Material 1. Stainless Steel

- *Design 1:* The Figures 2,3,4,5,6 gives the results for Total Deformation, Equivalent Stress, Shear stress, Life Analysis and Damage of material Stainless Steel.

Material 2. Stainless Steel with Nickel–Phosphorus (Ni–P) + Silicon Carbide (SiC) Composite Coating

- *Design 1:* The Figures 7,8,9,10,11 give the results for Total Deformation, Equivalent Stress, Shear stress, Life Analysis, and Damage of material Stainless Steel.

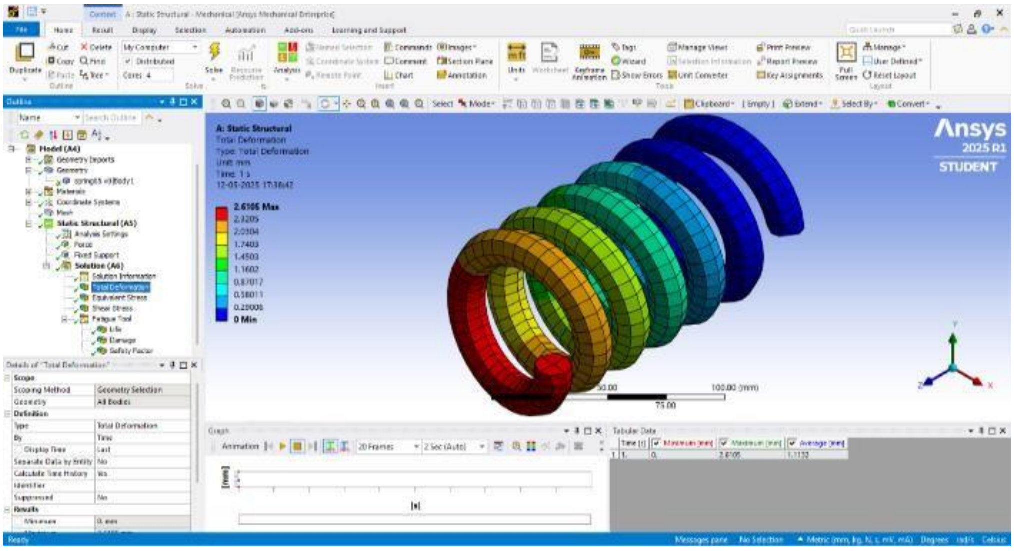
Table 2. Dimensions.

S.N.	Description	Dimensions in mm
1	Coil Diameter	65
2	Height	100
3	Number of coils	6

Table 3. Boundary conditions

S.No	Static Structural
1	Meshing(7mm)
2	Fixed support
3	Load(1000N)

Figure 1. Spring design.



A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
12-03-2025 17:38:47

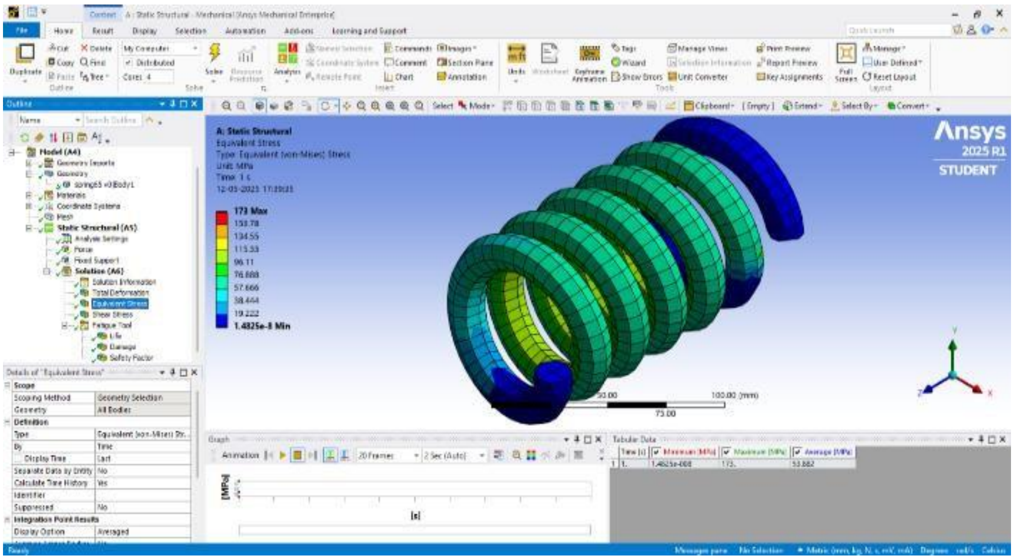
Details of "Total Deformation"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
By	Time
Display Time	Last
Separate Data by Entity	No
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
Minimum	0. mm

Tabular Data

	Time [s]	☑ Minimum [mm]	☑ Maximum [mm]	☑ Average [mm]
1	1.	0.	2.6105	1.1132

Figure 2. Total deformation.



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1 s
12-03-2025 17:39:33

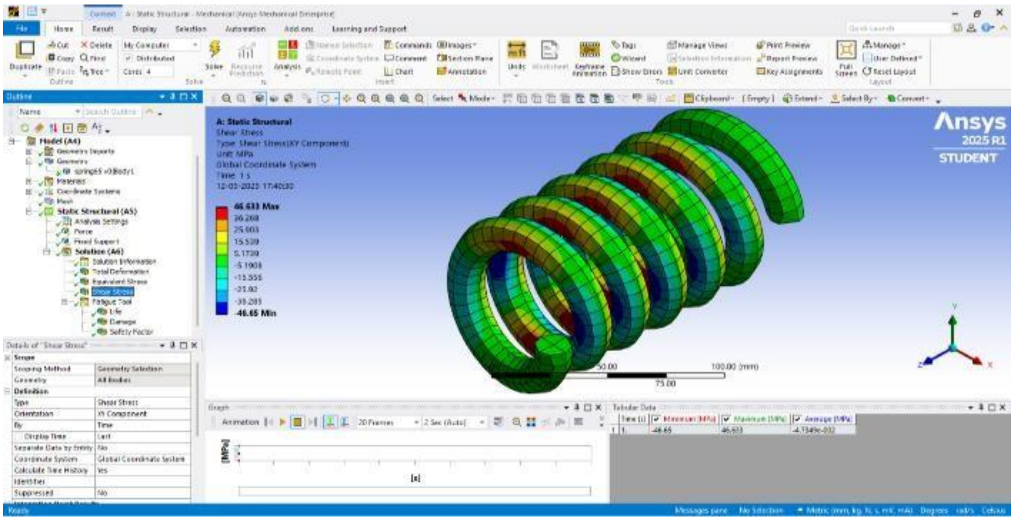
Details of "Equivalent Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent (von-Mises) Str...
By	Time
Display Time	Last
Separate Data by Entity	No
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged

Tabular Data

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]	☑ Average [MPa]
1	1.	1.4825e-008	173.	53.882

Figure 3. Equivalent stress.



A: Static Structural
Shear Stress
Type: Shear Stress(XY Component)
Unit: MPa
Global Coordinate System
Time: 1 s
12-03-2025 17:40:30

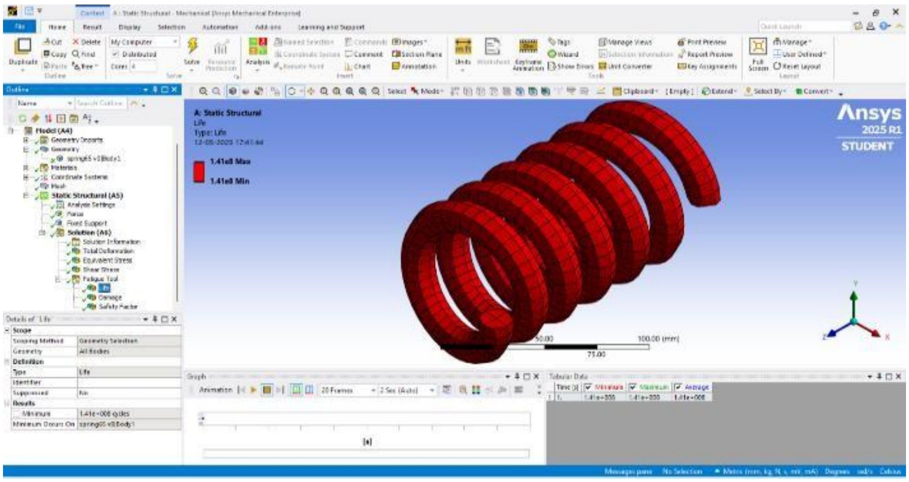
Details of "Shear Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Shear Stress
Orientation	XY Component
By	Time
Display Time	Last
Separate Data by Entity	No
Coordinate System	Global Coordinate System
Calculate Time History	Yes
Identifier	
Suppressed	No

Tabular Data

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]	☑ Average [MPa]
1	1.	-46.65	46.633	-4.7349e-002

Figure 4. Shear stress.



A: Static Structural
Life
Type: Life
12-05-2025 17:41:44

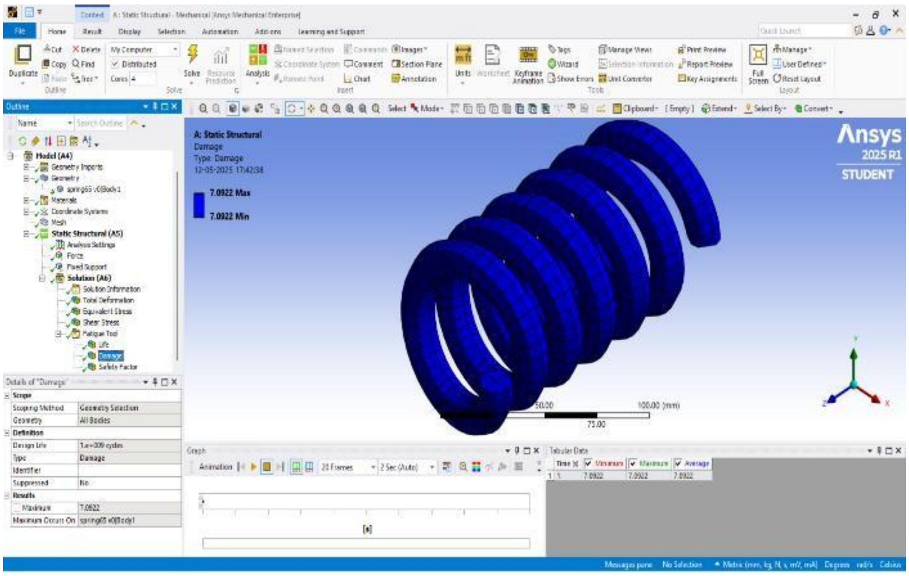
1.41e8 Max
1.41e8 Min

Details of "Life"

Scope
Scoping Method: Geometry Selection
Geometry: All Bodies
Definition
Type: Life
Identifier:
Suppressed: No
Results
Minimum: 1.41e+008 cycles
Minimum Occurs On: spring05 v0|Body1

Tabular Data
Time [s] | Minimum | Maximum | Average
1 | 1. | 1.41e+008 | 1.41e+008 | 1.41e+008

Figure 5. Damage.



A: Static Structural
Damage
Type: Damage
12-05-2025 17:42:38

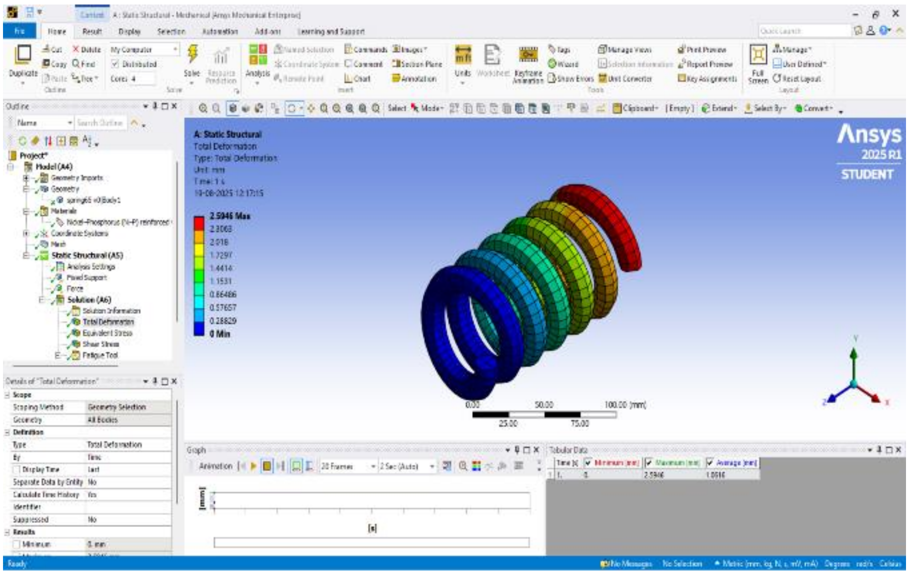
7.0922 Max
7.0922 Min

Details of "Damage"

Scope
Scoping Method: Geometry Selection
Geometry: All Bodies
Definition
Design Life: 1.e+009 cycles
Type: Damage
Identifier:
Suppressed: No
Results
Maximum: 7.0922
Maximum Occurs On: spring05 v0|Body1

Tabular Data
Time [s] | Minimum | Maximum | Average
1 | 1. | 7.0922 | 7.0922 | 7.0922

Figure 6. Life analysis.



A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
19-08-2025 12:17:15

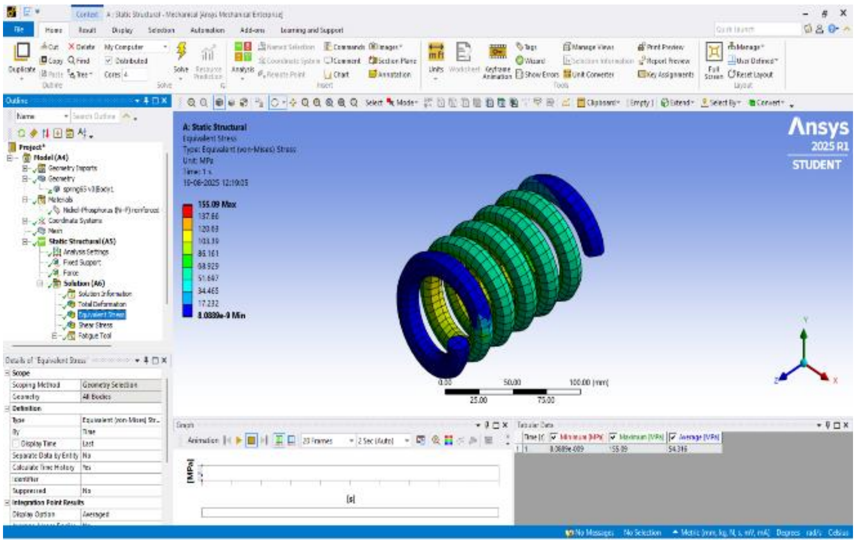
2.5946 Max
2.3063
2.018
1.7297
1.4414
1.1531
0.86486
0.57657
0.28829
0 Min

Details of "Total Deformation"

Scope
Scoping Method: Geometry Selection
Geometry: All Bodies
Definition
Type: Total Deformation
By: Time
Display Time: Last
Separate Data by Entity: No
Calculate Time History: Yes
Identifier:
Suppressed: No
Results
Minimum: 0. mm

Tabular Data
Time [s] | Minimum [mm] | Maximum [mm] | Average [mm]
1 | 1. | 0. | 2.5946 | 1.0516

Figure 7. Total deformation.



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1 s
10-06-2025 12:19:05

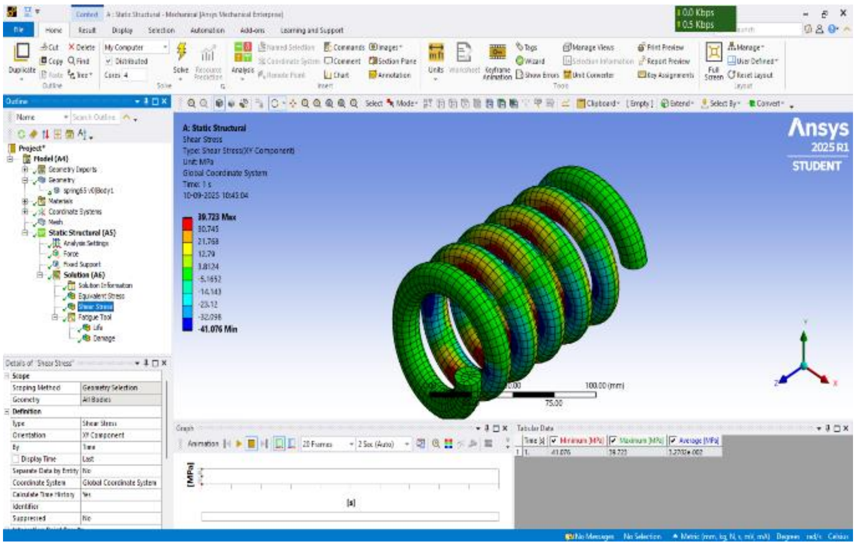
Details of "Equivalent Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent (von-Mises) Str...
By	Time
☐ Display Time	Last
Separate Data by Entity	No
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged

Tabular Data

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]	☑ Average [MPa]
1	1	8.0889e-009	155.09	54.316

Figure 8. Equivalent stress.



A: Static Structural
Shear Stress
Type: Shear Stress(XY Component)
Unit: MPa
Global Coordinate System
Time: 1 s
10-09-2025 10:43:04

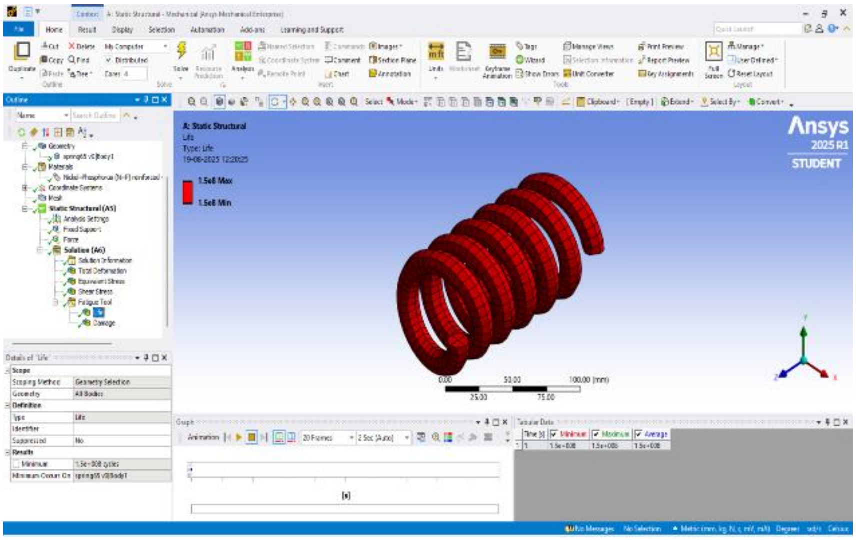
Details of "Shear Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Shear Stress
Orientation	XY Component
By	Time
☐ Display Time	Last
Separate Data by Entity	No
Coordinate System	Global Coordinate System
Calculate Time History	Yes
Identifier	
Suppressed	No

Tabular Data

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]	☑ Average [MPa]
1	1.	-41.076	39.723	1.2702e-002

Figure 9. Shear stress.



A: Static Structural
Life
Type: Life
19-06-2025 12:20:25

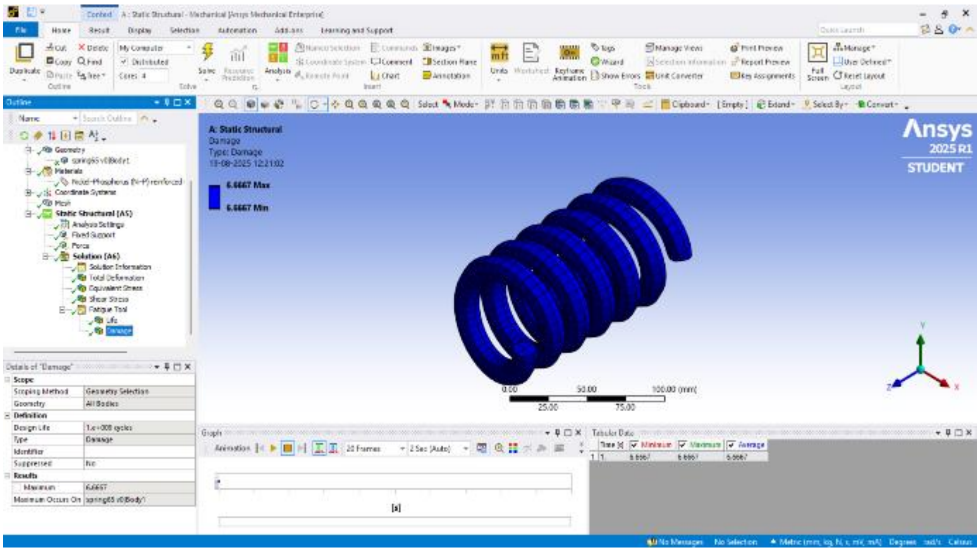
Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Results	
☐ Minimum	1.5e+008 cycles
Minimum Occurs On	spring65 v3[Body1

Tabular Data

	Time [s]	☑ Minimum	☑ Maximum	☑ Average
1	1	1.5e+008	1.5e+008	1.5e+008

Figure 10. Damage.


A: Static Structural
Damage
Type: Damage
19-08-2025 12:21:02

6.6667 Max
6.6667 Min

Details of "Damage"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Design Life	1.e+008 cycles
Type	Damage
Identifier	
Suppressed	No
Results	
Maximum	6.6667
Maximum Occurs On	spring65 v0(Body1)

Figure 11. Life analysis.

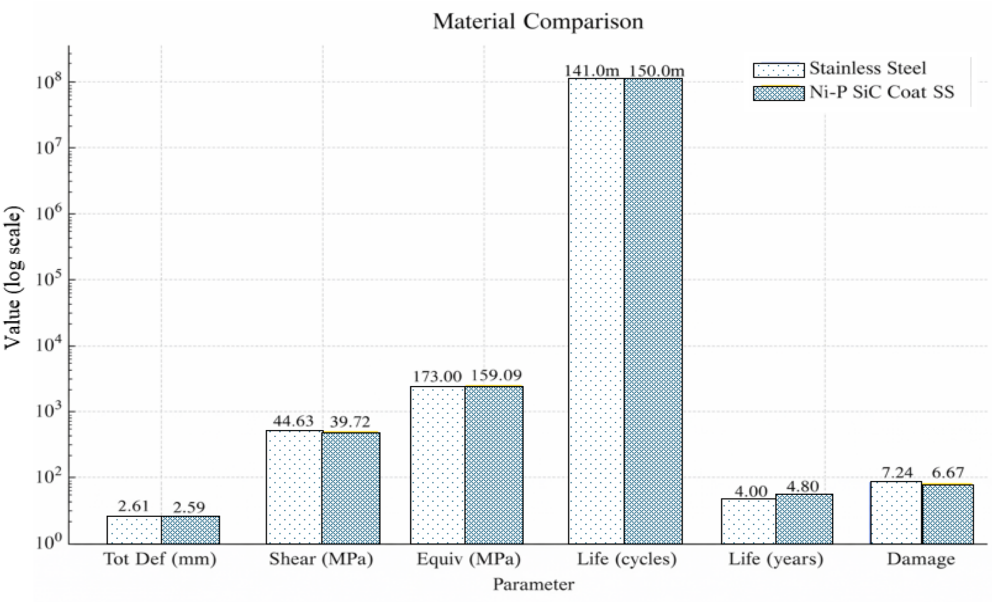


Figure 12. Comparison of analysis parameters for stainless steel vs. Ni–P + SiC coated stainless steel springs.

RESULTS

Fatigue Life Analysis Results

Fatigue life analysis for estimating the life and damage of the springs under cyclic loading condition has been conducted using ANSYS Workbench Fatigue Tool. The number to failure and cumulative damage was estimated via equivalent stress from the static structural analysis. This enabled a reliable prediction of the fatigue life improvement due to the Ni–P + SiC coating to be made.

Table 4 gives the information about Total deformation, Shear stress, Equivalent stress, Life, and Damage of both the springs:

Figure 12 illustrates a comparative visualisation of key analysis parameters—total deformation, equivalent stress, shear stress, life, and damage—for both materials. The Ni–P + SiC coated stainless steel spring shows superior performance across all parameters compared to the conventional stainless steel spring.

Table 4. Fatigue life analysis results.

Material	**Stainless Steel (existing material)**	**Stainless steel with Nickel–Phosphorus (Ni–P) + Silicon Carbide (SiC) composite coating**
Force applied	1000N	1000N
Number of coils	6	6
Total Deformation(max)	2.6105	2.5946
Shear Stress	44.633	39.723
Equivalent stress(max)	173Mpa	159.09Mpa
Life(max)	1.41e^08 (nearly 4years)	1.5e^08 (Nearly 4.8 years)
Damage(max)	7.238	6.6667

Results Summary

The life analysis results compare the performance of stainless steel and stainless steel with a Nickel–Phosphorus (Ni–P) + Silicon Carbide (SiC) composite coating for springs under an applied force of 1000 N, with each spring having six coils. The analysis shows that the stainless steel spring experiences slightly higher total deformation (2.6105 mm) compared to the stainless steel with Ni–P + SiC composite coating spring (2.5946 mm). In terms of shear stress, the composite-coated spring exhibits a lower value of 39.723 MPa versus 44.633 MPa for stainless steel. The equivalent stress values are close, with stainless steel at 173 MPa and the composite-coated spring at 159.09 MPa. Life expectancy is greater for the composite-coated spring at 1.5×10^8 cycles (approximately 4.8 years), compared to 1.41×10^8 cycles (nearly 4 years) for stainless steel. Lastly, the maximum damage is lower for the composite-coated spring (6.6667) than for stainless steel (7.238), indicating better durability and fatigue resistance under the given conditions. The comparison indicates that the Ni–P + SiC composite-coated stainless steel is superior to the traditional stainless-steel spring without a coating, the current material used in industry for helical springs. The otherwise identical spring coated with the composite material exhibits less deformation, reduced equivalent and shear stress, and longer fatigue life. The results of this study confirm that the addition of NI-P +SiC composite coating increases fatigue resistance and lifetime, therefore improving the durability and reliability of the helical spring material, compared to using currently acceptable conventional materials.

CONCLUSION

The comparative life analysis of stainless steel and stainless steel with Ni–P + SiC composite coating springs under a 1000 N load demonstrates that the composite-coated spring outperforms the uncoated stainless steel spring in multiple aspects. The composite coating reduces total deformation and shear stress, indicating improved stiffness and load-bearing capacity. Furthermore, the equivalent stress is lower in the coated spring, contributing to enhanced structural integrity. Most notably, the life expectancy of the composite-coated spring is significantly higher, and the maximum damage factor is lower, reflecting superior durability and fatigue resistance. Therefore, the application of Ni–P + SiC composite coating is an effective strategy for improving the mechanical performance and longevity of stainless steel springs in demanding conditions.

Future Scope

Future research can focus on further enhancing the performance of helical springs by exploring advanced composite coatings with different combinations of materials to achieve even higher fatigue resistance and lower deformation under heavy loads. Experimental validation of simulation results through physical testing would strengthen the reliability of the findings. Additionally, investigating the long-term effects of environmental factors such as temperature variations, corrosive media, and wear conditions on the performance of Ni–P + SiC coated springs could provide deeper insights into their real-world applications. Finally, optimizing the coating process parameters and exploring hybrid surface treatments, such as combining shot peening with composite coatings, may lead to significant improvements in service life and mechanical efficiency, especially for critical applications in aerospace and automotive industries.

REFERENCES

1. Burgul SR, Kulkarni AP. Fatigue analysis for helical compression spring for determining design alternatives for enhanced life and performance. Int J Technol Res Eng. 2015;2(7):1070–78.
2. Aibada N, Sundaram S, Kalani D, Loharkar PK. Review of studies on helical compression springs with a perspective of material, methods and failure. Int J Mech Eng Technol. 2018;9(3):936–45.
3. Bagaria WJ Jr, Doerfler R, Roschier L. Nomograms for the design of lightweight hollow helical springs. Proc Inst Mech Eng C J Mech Eng Sci. 2017;231(23):4395–406.
4. Rahul MS, Rameshkumar K. Multi-objective optimization and numerical modelling of helical coil spring for automotive application. Mater Today Proc. 2021;46:4847–53.
5. Chen L, Wu L, Fu H, Tang Y. Design and performance evaluation of polymer matrix composite helical springs. Polymers (Basel). 2022;14(18):3900.
6. Bagaria WJ Jr, Doerfler R, Roschier L. [Article title not provided]. Proc Inst Mech Eng Part C J Mech Eng Sci. 2017;231(23). doi:10.1177/0954406216665416.
7. Chen L, Wu L, Fu H, Tang Y. Design and performance evaluation of polymer matrix composite helical springs. Polymers (Basel). 2022;14(18):3900. doi:10.3390/polym14183900.
8. Aibada N, Sundaram S, Kalani D, Loharkar PK. Review of studies on helical compression springs with a perspective of material, methods and failure. Int J Mech Eng Technol (IJMET). 2018;9(3):936–945. Available from: http://iaeme.com/Home/issue/IJMET?Volume=9&Issue=3.
9. Romero-Resendiz L, El-Tahawy M, Zhang T, Rossi MC, Marulanda-Cardona DM. Hetero structured stainless steel: Properties, current trends, and future perspectives. Mater Sci Eng R Rep. 2022; 150: 100691.
10. Egbo MK. A fundamental review on composite materials and some of their applications in biomedical engineering. 2020 Jul 22.
11. Spasenović J, Blagojević I. Composite materials in automotive industry: A review. Industrija. 2023;49(2):57–68. doi:10.5937/industrija49-34540.
12. Parveez B, Kittur MI, Badruddin IA, Kamangar S, Hussien M, Umarfarooq MA. Scientific advancements in composite materials for aircraft applications: A review. Polymers (Basel). 2022;14(22):5007. doi:10.3390/polym14225007.
13. Farzaneh A, Mohammadi M, Ehteshamzadeh M, Mohammadi F. Electrochemical and structural properties of electroless Ni-P-SiC nanocomposite coatings. Surf Coat Technol. 2013; 276: 697–704.
14. Islam M, Azhar MR, Khalid MY, Burleigh TD. Electroless Ni-P/SiC nanocomposite coatings with small amounts of SiC nanoparticles for superior corrosion resistance and hardness. J Mater Eng Perform. 2015;24(11):4423–31. doi:10.1007/s11665-015-1801-x.
15. Chintada VB, Gurugubelli TR, Koutavarapu R. The impact of surfactants on the properties of electroless Ni-P-SiC coatings. Surf Coat Technol. 2022; 291: 126682.
16. Cui L, Li X, Li C, Zhu L, Zhang Q, Li Z, Liu H. Research on the corrosion resistance of electrodeposited Ni–SiC composites constructed for steel storage tank application. Materials (Basel). 2024;17(18):4616. doi:10.3390/ma17184616.
17. Ahmadkhaniha D, Lattanzi L, Bonora F, Fortini A, Merlin M, Zanella C. The effect of co-deposition of SiC sub-micron particles and heat treatment on wear behaviour of Ni–P coatings. Coatings. 2021;11(2):180. doi:10.3390/coatings11020180.
18. Gu Z, Hou X, Ye J. Design and analysis method of nonlinear helical springs using a combining technique: Finite element analysis, constrained Latin hypercube sampling and genetic programming. Proc Inst Mech Eng C J Mech Eng Sci. 2021;235(22).
19. Pyttel B, Brunner I, Kaiser B, Berger C, Mahendran M. Fatigue behaviour of helical compression springs at a very high number of cycles – investigation of various influences. Int J Fatigue. 2014; 60:101–9.
20. Shao C, Wang D, Zang Y, Cheng P. Surface residual stress release behavior of shot-peened springs. 2024 Mar 19.

21. Paredes M. Optimized dimensioning of helical compression springs. Eur J Mech A Solids. 2024;107:105385.
22. Juniani AI, Singgih ML, Karningsih PD. Design for manufacturing, assembly, and reliability: An integrated framework for product redesign and innovation. Designs. 2022;6(5):88.