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Numerical analysis of the stress leading to fatigue failure on a coil spring of the front suspension of a car

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Abstract. This study discussed the failure of the coil spring of a vehicle using a numerical method. The component was fabricated using ASTM A227. The coil spring was analyzed under three types of conditions, namely, flawless, defect of 0.2 mm, and defect of 3.5 mm. The simulation results show that the maximum shear stress of 745.8 MPa occurs on the spring with a defect of 3.5 mm. This value is close to the allowed shear stress, which is 799 MPa, but exceeded the yield strength of 731 MPa. This results in plastic deformation and contributes to failure due to fatigue.

1. Introduction

Transport vehicles require a good suspension system to dampen vibration, swings and shocks received as they travel along bumpy, hollow, and uneven roads [1]. These conditions are very uncomfortable and may cause accidents. The suspension is also expected to hold the load during some common vehicle maneuvers such as acceleration, braking or deflection while on the road [2]. The coil spring is one of the main components for dampening vibrations and shocks to the load so as to provide comfort and security while the vehicle is in motion [3].

Depending on the condition of their application, coil springs often sustain fatigue failure. This indicates that the tension received below by the coil spring from the maximum stress of the material while sustaining a dynamic load causes fatigue failure [4-8]. The yield strength of the material is also a criterion of failure. Components of automotive suspension must be changed with a traveling distance of 73,500 km, or every five years [9]. The fault of 13.18 % of 24.2 million vehicle tests was recorded [10].

With the development of computing technology, the numerical analysis method has become particularly suitable for use because it will increase the calculation efficiency, the cost-effectiveness as well as save time. Various numerical analysis methods are widely available, but the finite element analysis (FEA) has proven to be reliable in solving problems in the field of continuum mechanics [11].

2. Materials and methods

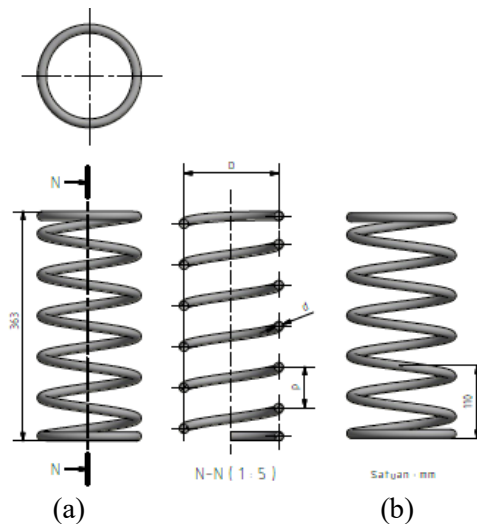
In this study, a spring made of ASTM A227 material was analyzed. Table 1 indicates the specifications of the material properties that were used as a reference for analyzing the coil spring using FEA. The coil spring was modeled using computer-aided design software. Figure 1 shows the coil spring that was modeled and analyzed by FEA. Table 2 indicates the size and dimensions of the coil spring used for the analysis.

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Table 1. Mechanical properties of ASTM A227 [4,5].

No.	Property	Value
1	Density, ρ	7800 kg/m ³
2	Elastic Modulus, E	200 GPa
3	Shear modulus, G	80 GPa
3	Allowable shear stress, τ_a	799 MPa
4	Yield Strength, σ_y	731 MPa
5	Poisson Ratio, ν	0.29

**Figure 1.** The modeling of the coil spring. (a) dimensions of the coil spring in 3D; (b) area of defect on the coil spring (unit: mm).**Table 2.** Size and dimensions of the coil spring used.

Dimension of coil spring					
Wire diameter, d (mm)	Outer diameter, D_o (mm)	Active coil, N_a	Pitch, p	Free Length, L_f (mm)	Correction factor, K_w
14	150	5	65	363	1,26

The analysis of the coil springs was performed when the loading was in a static state. Table 3 indicates that the entire coil spring received the load of the vehicle, five passengers dan goods. All the coil springs were considered to have received an equal load. The loads for the coil spring were classified as minimum and maximum.

$$\text{Minimum load on one coil spring of the vehicle} = \frac{12258 \text{ N}}{4} = 3064,5 \text{ N}$$

$$\text{Maximum load on one coil spring of the vehicle} = \frac{15690 \text{ N}}{4} = 3922,5 \text{ N}$$

Table 3. Load received on the coil spring

Vehicle (N)	Load	
	Passengers and goods (N)	Totally (N)
12258	3432	15690

The coil spring was analyzed under different conditions of defects that occurred on the surface of the coil through a FEA. The study was conducted using geometry and similar dimensional values as well as the same material. The coil spring was analyzed under three different conditions, namely, a faultless coil spring, a coil spring with a defect of 0.2 mm, and a coil spring with a defect of 3.5 mm. The shapes of the defect that occurred on the surface of the coil springs are shown in Figure 2.

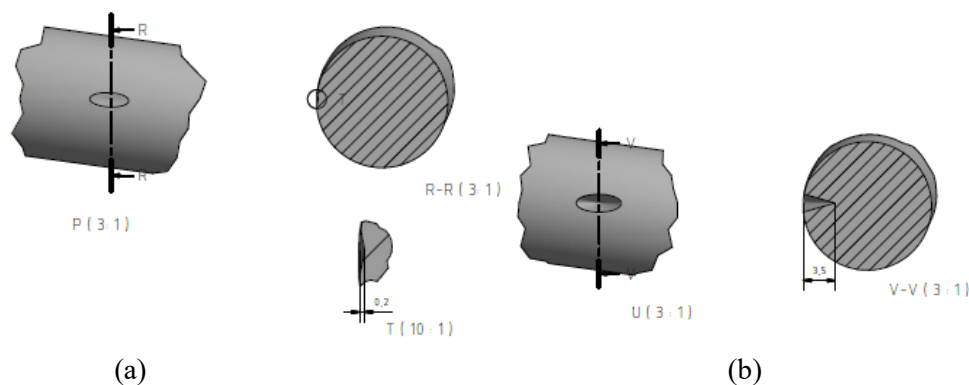


Figure 2. Shape of the defect formed on the surface of the coil spring: (a) defect up to 0.2 mm; (b) defect up to 3.5 mm.

3. Results And Discussion

Figures 3 and 4 illustrate in detail the occurrence of the von-Mises stress on the faultless coil spring using the FEA, Figures 5 and 6 on the coil spring with a defect 0.2 mm, and Figures 7 and 8 on the coil spring with a defect of 3.5 mm. Based on the results of FEA, the shear stress value of the ASTM A227 coil spring obtained was approaching the allowable shear stress, but its value exceeded the yield strength. Thus, coil springs with such defects undergo plastic deformation and are susceptible to failure.

The magnitude of the defect on the coil spring was affected by the location of the region or occurrence of nodes in terms of the stress distribution and displacement of the magnitude of the defect at each point of the coil. The node or region of maximal stress distribution and displacement magnitude lay at the same point, even though different loads were given, that is, the maximum or minimum load. Likewise, the stress distribution and displacement of magnitude were minimal. The nodes occurred at different points only in the case of minimal shear stress.

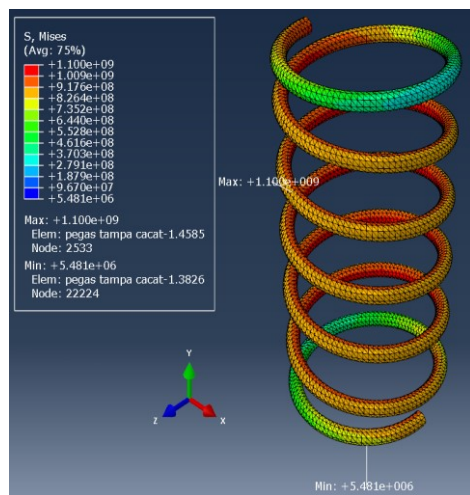


Figure 3. Contour of von-Mises stress on faultless coil spring given the maximum load.

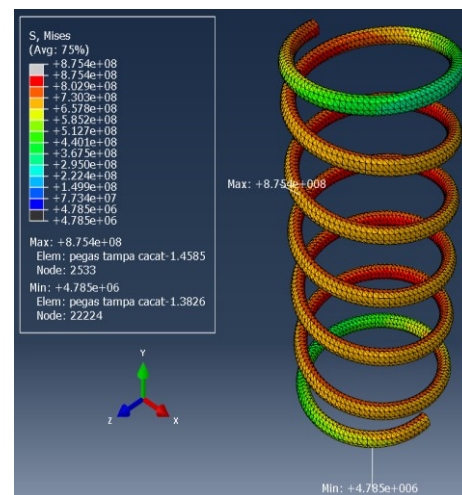


Figure 4. Contour of von-Mises stress on faultless coil spring given the minimum load.

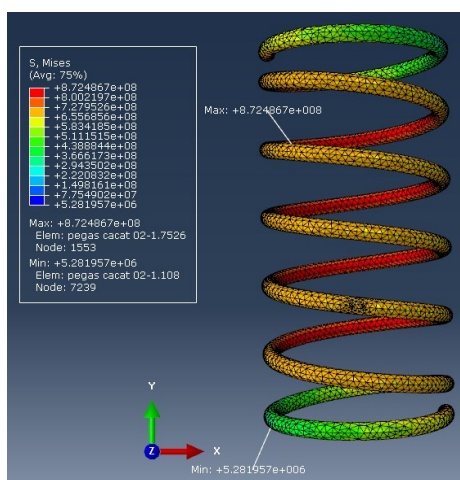


Figure 5. Contour of von-Mises stress on a coil spring with a defect of 0.2 mm given the maximum load.

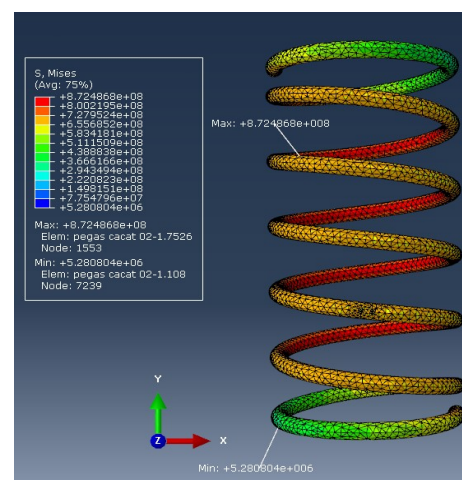


Figure 6. Contour of von-Mises stress on a coil spring with a defect of 0.2 mm given the minimum load.

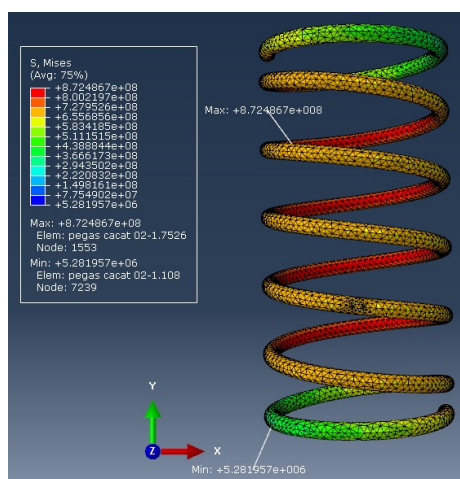


Figure 7. Contour of von-Mises stress on a coil spring with a defect of 3.5 mm given the maximum load.

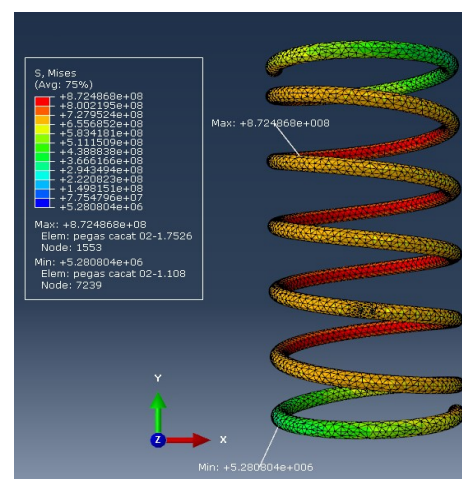


Figure 8. Contour of von-Mises stress on a coil spring with a defect of 3.5 mm given the minimum load.

4. Conclusion

Some conclusions could be drawn of the stress distribution and magnitude of displacement on the ASTM A227 coil spring as follow:

1. The maximum shear stress that occurred in the coil spring with a defect of up to 3.5 mm with the given maximum load was 745.81 MPa, and with the minimum load was 745.82 Mpa.
2. The minimum shear stresses that occurred in the coil spring with a defect of up to 3.5 mm with the given maximum load amounted to 736.9 MPa, and with the given minimum load was equal to 736.94 MPa. However, it was in the opposite direction.
3. The coil spring with a defect of up to 3.5 mm had undergone plastic deformation and was susceptible to failure, and (d) the condition of the defect in the coil spring affected the location of the occurrence of the node or stress distribution and magnitude displacement.

5. References

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