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Failure Analysis of the Leaf Spring of Truck Colt Diesel Using Finite Element Method

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Abstract. Damage is often experienced by leaf springs of diesel trucks, known as premature failure and is need to be analyzed. Thus, this study aims to analyze the causes of failure of leaf springs through analytical and numerical analyses. Hardness testing was performed using the Rockwell method. Microstructure was observed using scanning electron microscopy to identify the fracture surface. Analytical and numerical analyses were used to obtain the load distribution of each spring. The analysis results of load distribution on each spring were 26.95 kN. The chemical composition of the specimen shows that the material was tested according to AISI 5150 standard. The hardness value of leaf springs tested was HR_B 106.9. The Result of numerical and analytical shows that the strain, stress and deformation of leaf springs with maximum values occurred at the near of hole of spring. The K_I value $\approx K_{IC}$, therefore this may cause crack propagation. The failure of leaf springs was caused by fatigue during the operation marked by a beach mark and the normal stress is far below the specimen fatigue strength.

Keywords: Leaf springs, Crack initiation, Finite element method, Fatigue fracture, Stress intensity factor

1. Introduction

A leaf spring is one of the suspension system commonly used for the suspension in wheeled vehicles, function as vibrationdamper, as well as to support the vehicle frame [1].The leaf springs used in cargo vehicles such as trucks, originally deferred to as a semi-elliptical spring. Accordingly, the truck experienced load on the center point towards the rear of its body, resulted larger deflection compare with forepart [2].

The leaf springs always receive a high dynamic load and often experience fatigue failure that occurs after the component is used for a certain period in its operation [2,3]. Failure due to fatigue is a fracture mechanism that can be identified through 3 stages, the first stage is initiation of crack, then crack propagationand the final stage is fracture [4,5].

Fatigue failure is the most common failure in automotive components, particularly those involvingspring on trucks. This is due to automotive components often experience excessive load and shocks that occur due to the unevenness of the road through the wheel. The load occurs suddenly so that the wheels up and down with irregular frequencies. Leaf springs are more affected by the fatigue load, because the springs hold the mass of the entire car [6].

The spring is produced by means of hot forming such as hot rolling depend on the expected specification of spring function manufactured [2]. Leaf spring is an automotive components produced from high carbon steel as its raw material (C > 0.5%) [3].

Colt diesel truck is a small capasitytruck with the container tub on rear of its part. The trucks often carry over maximum capacity of load and operated on the unevenness of the road. The truck was operated sincetwo years ago with the speedo meter numbers of 572 km, but the leaf spring number 8 experience the fracture. It is known that thelife time of the spring still far under design life time. Thus, the failure of the leaf spring needs to be assessed experimentally and analyzed numerically**.**

The main objective of this research is to analyze the causes of spatter spring failure used by colt diesel trucks experimentally and numerically. Known causes of failure, so that anticipated the occurrence of the same failure in the future and can reduce serious accidents on the highway.

2. Material and Method

2.1. Material and visual inspection

The material used in this study is a fracture leaf springs of colt diesel truck. The springs experience fracture at the usage of 572 km operating as shown in Fig. 1. This Materialwas supplyed by a mechanical workshop, then it was identified the vehicle types and the loads capacity allowable using thename plate. The arrows in Fig. 1 shows the fracture part of the leaf springs near the bolt hole.

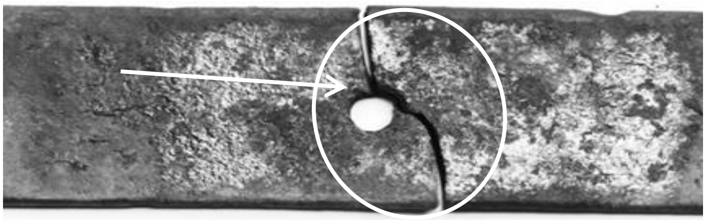

Figure 1. Material for research object

The fracture surface was visually evaluated asshown in Fig. 2. The figure shows the spring number eight experienced the fracture on the bolt hole.

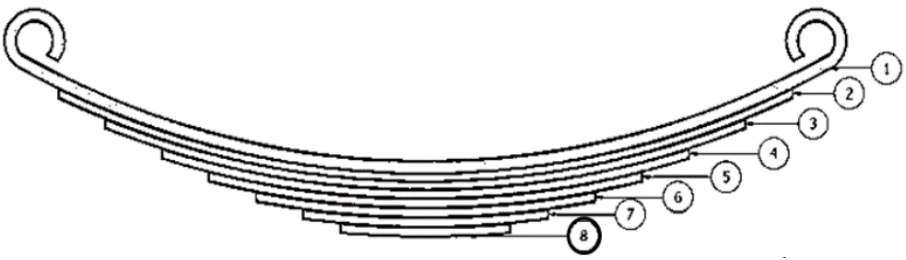

Figure 2. Failures leaf spring occurred at number eight

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Visual evaluation of the leaf spring failurewas focusedin the area of bolt hole. Image of the failure surface was taken for showing the historical failure data of failure. Theimage of surface marked initial crack, beach mark and final crack as shown in Fig. 3.

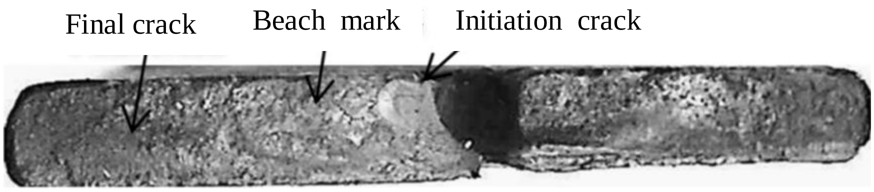


Figure 3. Image of fracture surface of leaf spring

The surface of the fracture spring identified as a fatigue fracture, characterized by a crack initiation area, which subsequently occurs crack propagation in line with fluctuating loading and final fracture [7,8]. The loads leaded by springs on the vehicle are known as fatigue loads because of their dynamic nature. The leaf springs fracture surface was evaluated using scanning electron microscopy (SEM) image. Throught SEM image, failure region can be evaluated whether there is a preliminary defect in the leaf springs as shown in Fig. 3.

Hardness test was performed using Rockwell Type Zwick/Roell ZHR to measure the surface hardness of leaf spring specimens. The indentor used was a steel ball of 1/16-in in diameter and a 100 kg of loading. The size and form of hardness sample is shown in Fig. 4 Configuration of the specimen and the points for hardness test.

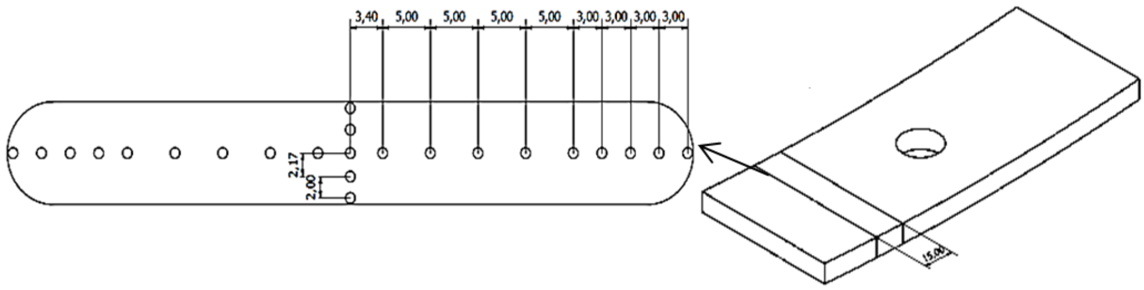


Figure 4. Configuration of the specimen and the points for hardness test

2.2. Chemical Composition Evaluation

Evaluation of chemical composition was performed on test specimens of failure leaf spring. A small part of spring sample was taken and tested. The elements of spring material are shown in Table 1 comparing to the chemical composition of the ASTM standard AISI 5150. Table 2 shows the mechanical properties of AISI 5150 used for finite element analysis.

Table 1. Chemical composition of the material (% wt)

Element	Test Result	AISI 5150 [9]
C	0.529	0.480 – 0.530
Si	0.293	0.150 – 0.300
Mn	0.762	0.700 – 0.900
P	0.0021	≤ 0,0350
S	0.02	≤ 0.04

Table 2. Mechanical properties of AISI 5150 steel

Mechanical Properties of Materials	Value	Unit
Modulus Young (E)	140	GPa
Poison's ration ($\boldsymbol{\mu}$)	0,28	-
Density (ρ)	7850	kg/m^3
Yield Strength (σ_y)	360	MPa
Tensile Strength(σ_B)	675	MPa
Shear Modulus (S)	80	GPa
Fracture Toughness, K_{IC} [10]	23	MPa.m$^{1/2}$

2.3. Analytical Analysis

Analytical analysis is performed to obtain the load distribution on each wheel, either the maximum load or minimum load during the operation of the leaf springs. As it is known that the fine crack found in the material that leaded a bending load and resulted the stress intensity factor (K_I) around the crack tip. When the value of $K_I > K_{IC}$ (fracture toughness), the crack propagation will occur, but when $K_I < K_{IC}$, crack does not spread. Based on this understanding, the stress intensity factor was calculated using available data of the failure life spring [11-13]. Further analytical solution is explained in detail in sub sections 3.3.

2.4. Numerical Analysis

The simulation of collected data was done on the bolt hole area on leaf springs number eight. The usage of hole area due to the fracture failure is around it. From the result of simulation, the stress distribution known, as well as stress intensity factor and strain also obtained [14,15].

The steps and simulation process for numerical analysis were done using FEM software by giving fixed support on the spring eye. The loading type used was centralized load given on the bottom of the spring. The truck loading can be calculated by analytical analysis as shown in Fig. 5.

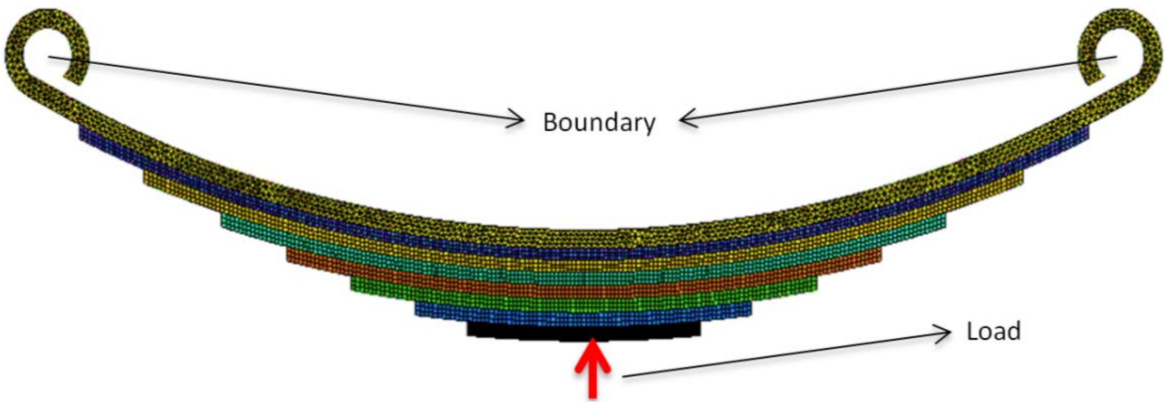


Figure 5. Determination of the boundary condition and loading

The meshing steps used the obtained nodes number of 633438 and the number of elements of 5280. The meshing result of finite element analysis for all spring is shown Fig. 6.

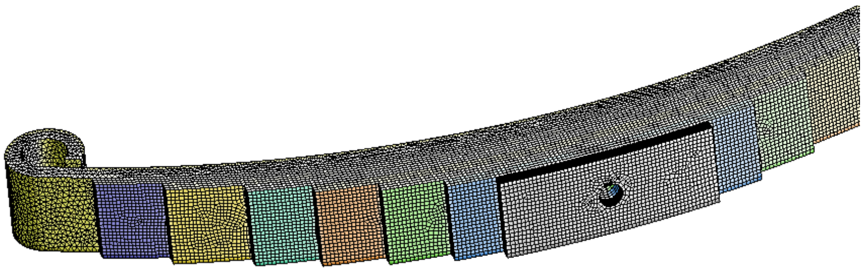
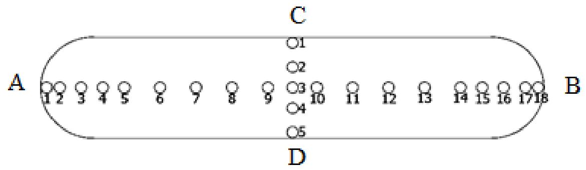


Figure 6. Meshing results on leaf springs for FEM analysis

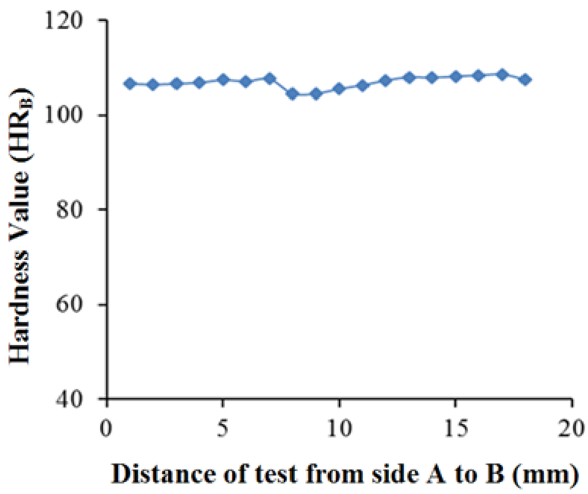
3. Results and Discussion

3.1. Hardness of Failure Leaf Spring

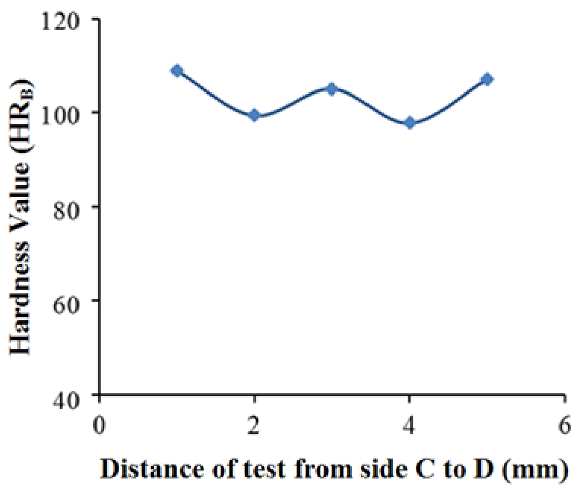
The results of hardness test areshown in Fig. 7 horizontal axis from point A to B and vertical axis from C to D in the sum of 22 points. The distance between point approximately 2 to 5 mm (ref. to Figure 7.a). The hardness in the area close to the bolts hole or in middle of the spring is lower than of the ends of leaf spring. It shows that, the materials toughness on the center of the leaf spring higher than of the spring ends. This result is in agreed well with the result reported by previous researchers [2].



(a)



(b)



(c)

Figure 7. Material hardness testing. (a) Hardness test point at the spring. (b) Inner surface hardness graph from A to B side (see Figure 10.a). (c) Surface hardness graph from side C to D (see Figure 10.a)

The sample of leaf spring surface hardness yields different values between the center and the edges. Hardness test results show that, in the horizontal directions of A to B are 104.6 HR_B

minimum and 108.5 HR_B maximum. The difference in hardness value is insignificant only 3.6 %. The same results are encountered in directions of C to D are 97.8 HR_B minimum and 107.1 HR_B maximum remain under 10 % namely 8.7 %. The mean hardness was 106.5 HR_B in the A to B direction and 102.5 HR_B for the C side to D direction. The mean of the overall hardness value is 104.5 HR_B. It can be concluded that no hardening of the damaged leaf springs as seen from hardness is not much different between the points around the fracture and outside the point.

After testing the hardness depth reaches 22 mm from the outer surface of leaf springs. Hardness of the AISI 5150 material according ASTM standard is 92 HRB, while the hardness value of leaf springs of the results is 106.9 HRB. This hardness value indicates that the spring had undergone heat treatment and shot peening as surface treatment for residual stress regenerating. The high hardness difference between the value of the standard and the test results can decrease the ductility or tinkering occurs during the spring operation. This may cause the spring elasticity function to tend to decrease and when the maximum spring loading will be easy to crack [16,17].

3.2. Leaf Spring Fracture Evaluation

Microscopic observations with magnitudes of 6000 on the fracture surface of the spring identified that the crack occur around the bolt hole. The crack starts on the bolt portion then propagate to the cross section of the spring. Figure 8 shows the image of crack area.

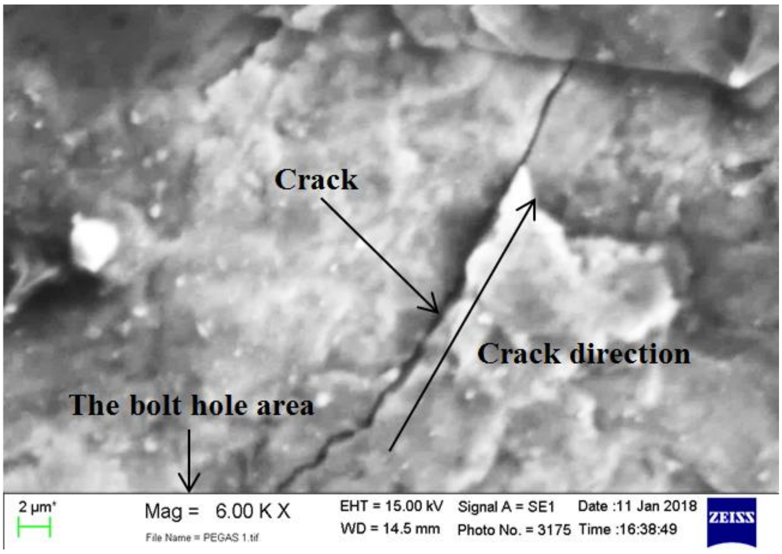


Figure 8. Fracture surface spring shows crack area marked with iniation crack

3.3. Analytical and Finite Element Analysis

Analytical analysis aims to obtain the value of stress intensity factor on the elements with crack. For this propose, it is needed the weight of unloaded truck of 3000 kg, the vehicle weight during operation is 11000 kg and maximum allowable vehicle load standard is 7500 kg. The load distributed on each wheels is calculated using Eq. (1) [2,18].

$$F = \frac{m \times g}{4} \tag{1}$$

Where m is a vehicle weight of 11000 (kg), g is the gravity of 9, 8 (m/s^2). The maximum load leaded by each wheels is 26.950 kN.

Figure 9 shows a single-edge-crack-at-hole specimen. Obtaining a value intensity factor (K_I) is calculated using Eq. (2) in the basis of data shown in Fig. 9 [19].

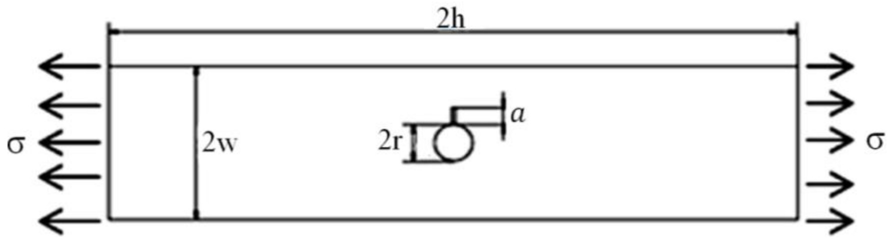


Figure 9. Crack configurations single-edge-crack-at-hole specimen for the calculation of K_I (radius, r = 5mm, wide, w = 25mm)

$$K_I = \sigma\sqrt{(\pi a)F_{hs}} \tag{2}$$

Where a is the crack length. The crack length is obtained from the visual observation with the value is 4.9 mm, σ is the stress that occurs in the spring (specimen). Stress occurring at the spring is calculated using finite element analysis. From finite element analysis as shown in Fig. 10 with a given load of 26950 N, the maximum value of 132.84 (MPa) is obtained. F_{hs} is a limiting correction factor calculated by referencing to previous research methods [19]. The results of boundary correction factor analysis obtained value of 2.49.

After calculation of stress intensity factor (K_I) on the spring that experienced an initial crack of 4.9 mm, then obtained K_I value of 22.53 MPa$\sqrt{m}$.

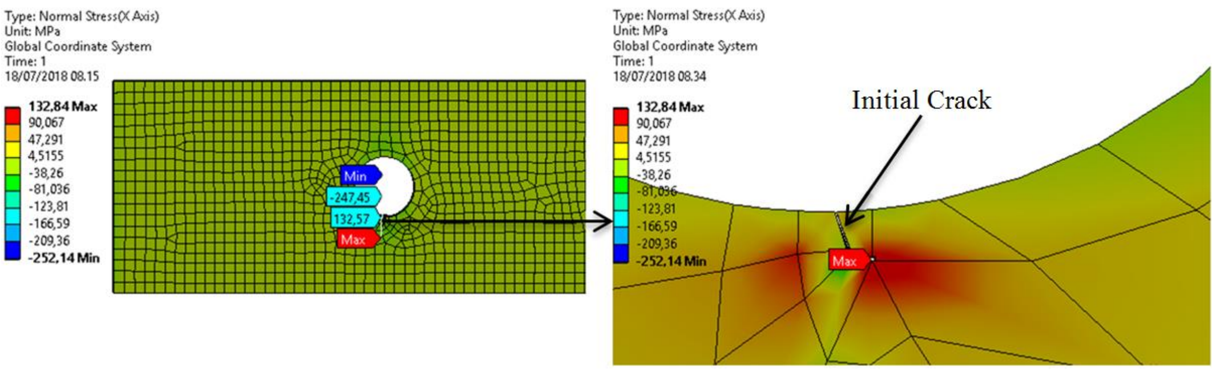


Figure 10. The normal stress of leaf spring

The maximum stress value received by spring is smaller than the yield strength of AISI 5150 material equal to 218 MPa, so it does not cause the spring number eight deformed and the mean stress on the spring number eight is well distributed.

The result of strain occurring on leaf spring number eighth with load of 26950 N shown in Fig. 11. The value of maximum strain resulted by simulation was 8.67x10^{-4} at bolt hole area and minimum was -6.27x10^{-4}. The largest shape change was on the eight spring bolt holes.

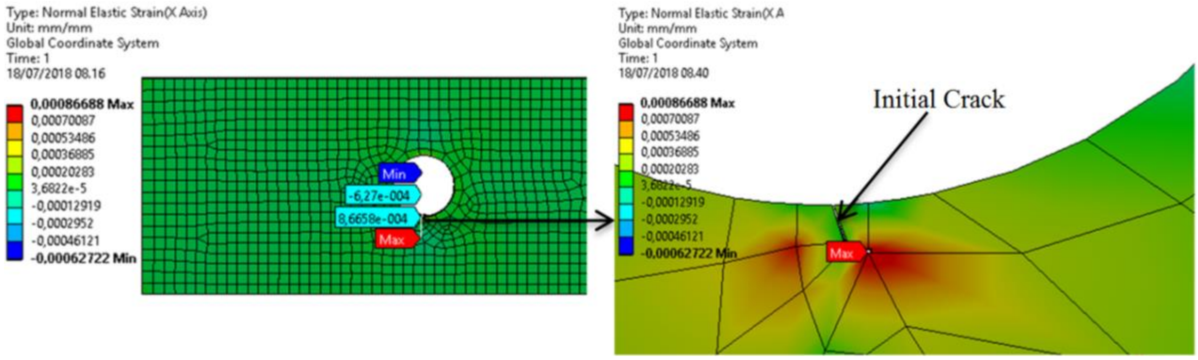


Figure 11. The normal strain of leaf spring

The results of finite element method analysis for obtaining the stress intensity factor (K_I) on leaf springs by modelling the crack length of 4.9 mm in the bolt edge crack are shown in Fig. 12.

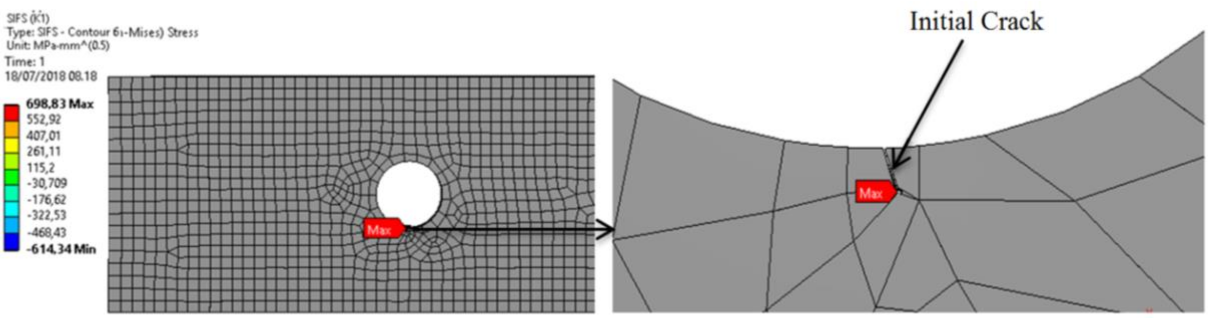


Figure 12. Stress Intensity Factor (K_I)

The stress intensity factor analysis yielded a value of 22.09 MPa$\sqrt{m}$ with a load of 26950 N. The analysis results show that the value intensity factor is close to the fracture toughness ($K_I \approx K_{IC}$). Therefore, this can cause crack propagation due to dynamic loads [9,10]. This fact states that this is one of the causes of leaf spring failure.

4. Conclusions

The failure analysis of the leaf spring through microstructure observation, analytical and numerical analysis yielded the following conclusions:

1. The truck load is approximately 11000 kg that is exceeding from 7500 kg of standard limit, above is approximately 17% of the lift power truck.
2. The maximum stress occurs on eighth sequence of leaf spring is 132.84 MPa. This stress lower than yield stress of AISI 5150 of 360 MPa.

3. The result shows that the Stress Intensity Factor has a value of 22.53 MPa, the value intensity factor is close to the fracture toughness ($K_I \approx K_{IC}$), $22.53 \approx 23$ MPa$\sqrt{m}$. The crack propagation occurred due to dynamic loading.
4. Failure was caused by fatigue fracture characterized by existent beach mark on the fracture surface.

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