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Study of leaf spring fracture behavior used in the suspension systems in the diesel truck vehicles

Study of leaf spring fracture behavior used in the suspension systems in the diesel truck vehicles

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Abstract. The leaf spring is frequently applied on a vehicle such as used on the truck and it is one of the machine element suspension systems. It needs to have an excellent resistance to the fracture propagation to avoid failure that could lead to severe accidents. Fracture failure on the leaf spring is frequently experienced especially on diesel trucks, known as premature failure. Therefore, this case is needed to be studied and investigated. The purpose of this study is to investigate the cause of failure on the broken leaf spring by counting analytically the stress intensity factor (K_I) occurred near the crack tip. Moreover fracture surface observation conducted by Scanning Electron Microscope (SEM) to find out whether there is or not an initial crack and crack propagation direction. This present study describes the experimental work and analytical analysis of theleaf spring used on Diesel Truck Vehicle. Hardness testing was performed using the Rockwell method. The chemical composition testing on the leaf spring material was found that the material in accordance with AISI 5150 standard. The hardness value of leaf springs tested of about 106.9 HRB. The result of analytical analysis shows that the maximum value of stress intensity factor (K_I) occurred near the crack tip at the near the hole of leaf spring. In this case the value of K_I is higher than thevalue of the fracture toughness (K_{IC}) of the leaf spring material. Therefore, this result could be inferred that crack propagation happened starting from initial crack tip which is located near the hole on the leaf spring. The failure of leaf springs also caused by fatigue crack propagation due to dynamic loading during the operation marked by appearance the beach mark on the fracture surface.

1. Introduction

One of the components for the suspension system that is often used in a vehicle such as Truck is a leaf spring [1]. The use of leaf springs on truck vehicles in addition to holding the load also serves as a vibration damper. Furthermore, it is known that loading on the truck is at the midpoint on the back of the vehicle cart [2].

In general the using of the leaf spring on the truck often experience failure due to fatigue load. In this case, fracture occurs because of an initial fine crack in the part of high the stress concentration on the spring surface or in other parts. The crack propagation behavior occurred usually starts from crack initiation and then it is followed by crack propagation and caused a final fracture [3-5].

Since the failure by fatigue fracture is the most common failure in automotive components such as crankshaft [6] as well as those involving spring on trucks. In addition to, leaf spring especially as automotive components often experience over load and vibration that occur due to the unevenness of the road. Therefore, the load occurs suddenly so that the wheels up and down with irregular frequencies. Many cases indicated that Leaf springs are affected by the dynamic loading [1].

The material used for leaf springs is usually a plain carbon steel having 0.90 to 1.0% carbon. The leaves are heat treated after the forming process. Heat treatment of steel spring products will produce greater strength and therefore greater load capacity, greater deflection range and better fatigue properties [7]. The leaf spring is produced using hot rolling depending on the expected specification [2].

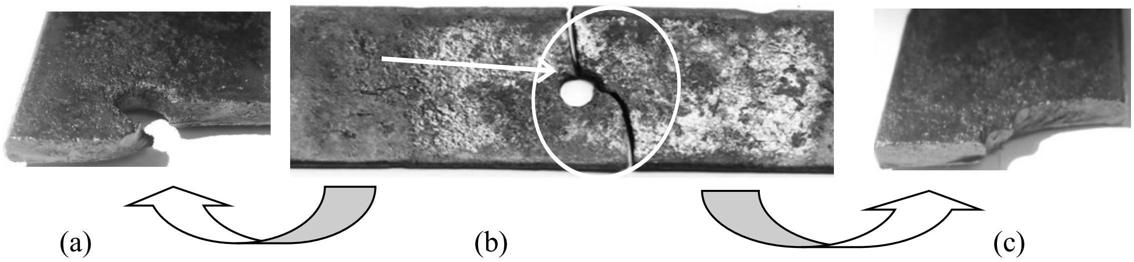
This study will examine the fracture of leaf springs used in a Colt diesel truck. The earliest known data is a small capacity truck with a container tank behind its part. Several times, trucks carry more load capacity and operate on uneven roads. Furthermore, the truck was operated for two years with a distance of 572 km, until the leaf spring number 8 experienced a broken failure. Therefore, the failure of leaf springs needs to be investigated experimentally and analyzed analytically.

The purpose of this study is to investigate the causes of spring failure used on the diesel trucks experimentally and analytically. When the causes of failure found, accordingly the same failure can be anticipated in the future and can also prevent vehicle damage.

2. Experimental Procedure

2.1. Broken leaf spring and visual inspection

The object research used in this study is the leaf fracture spring used in colt diesel trucks. Leaf springs experience fracture after the vehicle runs up to a distance of about 572 km. Broken leaf spring as shown in Figure 1. This material was obtained from a mechanical workshop, and then identified the type of vehicle and the allowable load capacity. The fracture that occurs in the leaf spring is near the bolt hole as indicated by the arrow.



(a) (b) (c)

Figure 1. (a) Broken leaf springs on the left side of Fig. 1(b). (b) Broken leaf spring for research object. (c) Broken leaf springs on the right side of Fig. 1(b).

Figure 2 shows a schematic drawing that explains the arrangement of springs from number 1 to number 8. In this case the broken one is spring number 8 as shown in Figure 2.

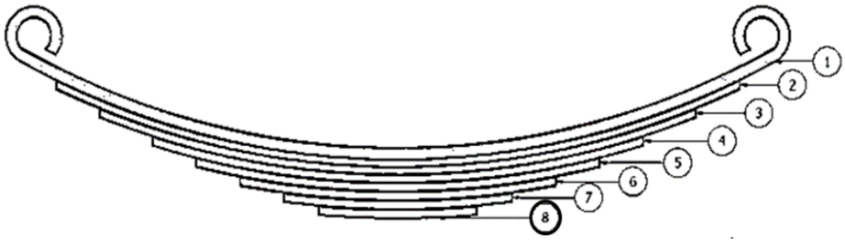


Figure 2. Schematic drawing of the arrangement of the leaf springs from No. 1 to No. 8 (broken spring).

Visual observations on the fracture surface of leaf spring evaluated were around the bolt hole area. From visual observation, it was found that there was an initial crack on the side of the bolt hole as shown in Figure 3. Furthermore, the beach mark can be seen on the fracture surface. This finding indicates that the spring has experienced fatigue fracture [8].

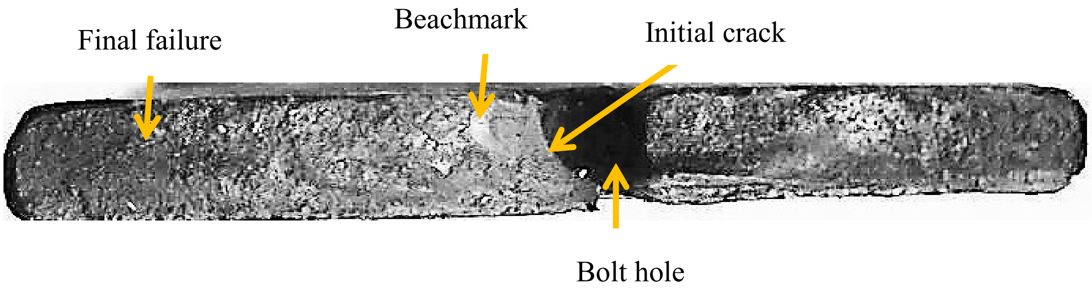


Figure 3. Picture of the fracture surface of the leaf spring of number 8.

Figure 4 shows that the image taken from initial crack tip area as shown in Figure 3. It can be seen that the crack initiationoccurred here which is characterized by relatively smooth fracture surfaces which indicates that fatigue cracking has occurred.

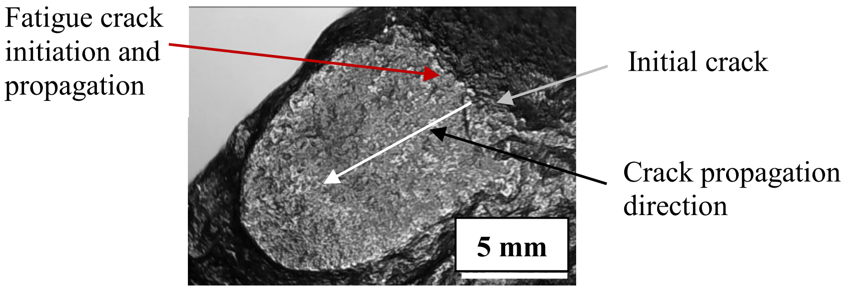


Figure 4. Fracture surface image taken from initial crack tip area of Figure 3.

Fracture surfaces of leaf springs (Figure 3 and 4) show that fatigue crack propagation has occurred which starts from the initial crack, then crack propagation occurs in line with increasing dynamic load so that the final fracture is split in two parts [8][9].

In this study also conducted a hardness test using Rockwell Type Zwick / Roell ZHR to measure hardness on the surface and core of leaf spring specimens [10]. The indentor used is a steel ball with a diameter of 1/16 in and 100 kg of loading. The hardness test specimen is shown in Figure 5.

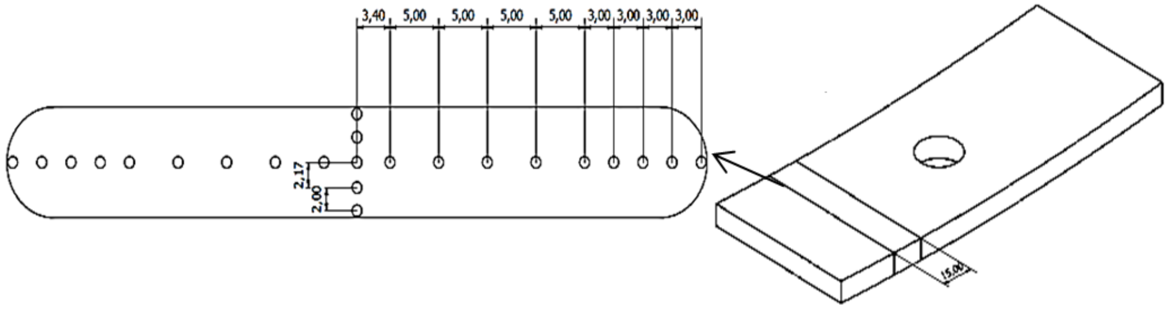


Figure 5. Specimen configuration with hardness testing points marked with small circles (o).

2.2. *Material Properties Chemical Composition*
Assessment of chemical composition was performed on test specimens of failure leaf spring. A small part of spring sample was taken from the broken spring and then tested. The elements of spring material are shown in Table 1. Furthermore, the results found comparing to the chemical composition of the ASTM standard AISI 5150. The mechanical properties of AISI 5150 as shown in Table 2.

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} [11]	23	MPa.m$^{1/2}$

2.3. *Analytical Analysis*
Analytical analysis is conducted to get the load distribution on each wheel, and then calculates to find the stress ($\boldsymbol{\sigma}$) that occurs in the spring. By knowing the amount of stress that occurs in the spring, the value of stress intensity factor that occurs around the crack tip can be determined. As it is known that if there is a fine crack in a material such as a spring, then around the crack tip will appear the stress

intensity factor (K_I). If the K_I value that occurs near the crack tip is greater than the value of fracture toughness (K_{IC}) of the spring material, it will cause crack propagation.

Based on this understanding, the stress intensity factor is calculated using the data available from the broken spring [12][13]. Furthermore, analytical solutions will be explained in detail in sub sections 3.3.

3. Results and Discussion

3.1. Hardness on the Leaf Spring

The hardness test results in the horizontal direction from point A to B and the vertical direction from point C to D as shown in Figure 7. The distance between test points is approximately 2 to 5 mm (see Figure 6.a). Hardness in the area close to the bolt hole or at the core is lower than the hardness value in the part close to the side of the spring surface. It shows that the toughness of the material in the center of the leaf spring is higher than the part on the outer side of the spring. Therefore this spring is very susceptible to fracture. This result is in accordance with the results reported by previous researchers [2][7].

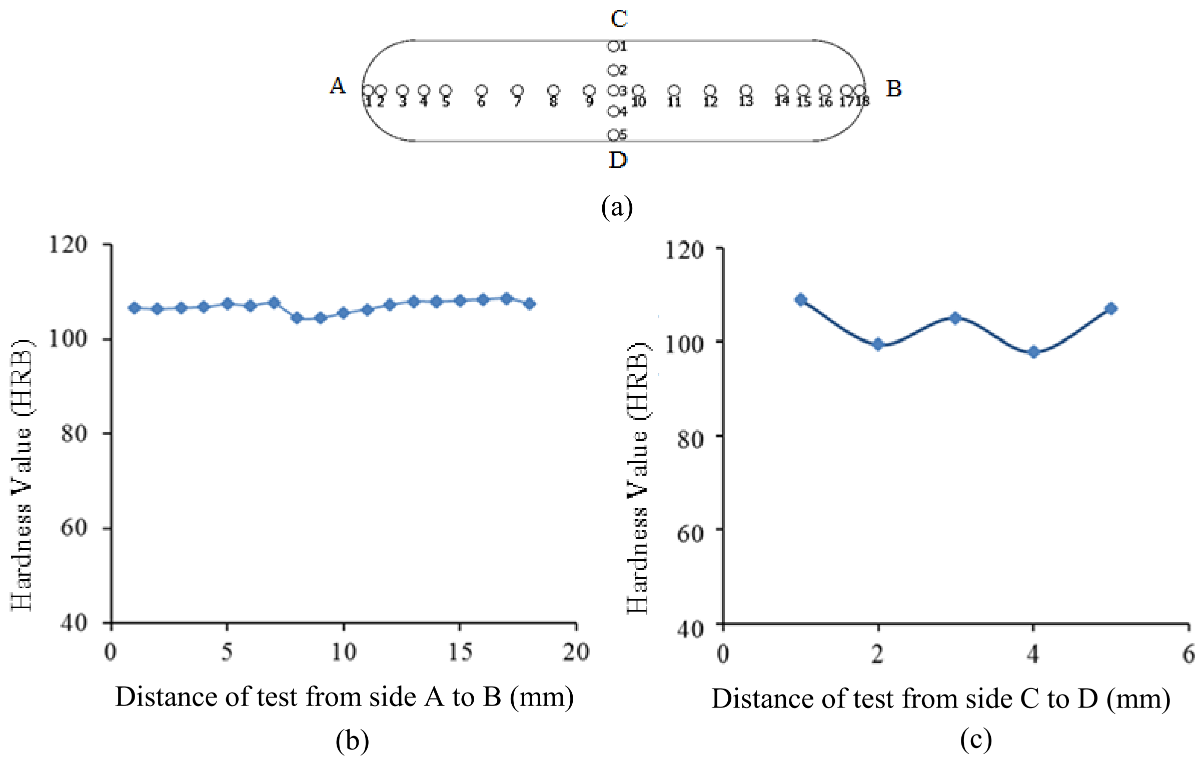


Figure 6. Curve of hardness on the Leaf Spring. (a) Hardness test point at the spring. (b) Curve of hardness in the inner section in the direction from A to B (see Figure 6 (a)). (c) Curve of hardness in the inner section in the direction from C to D (see Figure 6 (a)).

The leaf spring cross section hardness yields different values between the center and the edge side. Hardness test results show that, in the horizontal directions from A to B are 104.6 HRB for minimum value and 108.5 HRB for the maximum value. The difference in hardness value is insignificant only 3.6%. The same results are encountered in directions from C to D are 97.8 HRB minimum and 107.1 HRB maximum where the results remain under 10% namely 8.7%. The mean hardness was 106.5

HRB in the A to B direction and 102.5 HRB for the C side to D direction. The mean of the overall hardness value is 104.5 HRB. It can be concluded that there is no hardening that cause the leaf springs damaged. This matter as seen from hardness value is not significantly different between the points around the fracture and at the point on the edge.

The high hardness difference between the value of the standard and the test results can decrease the ductility. This may cause the spring elasticity function to tend to decrease and when the maximum loading on the spring will easily happened crack extension [7][13][14].

3.2. SEM Observation on the Fracture Surface

In reality, leaf springs as a suspension system in vehicles always receives dynamic loads and sometimes until they experience failure of fatigue fractures. Therefore, the fracture surface was necessary to investigated using scanning electron microscope (SEM) [14]. 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. Furthermoreit can be explained as in Figure 7. Where, Figure 7 shows a series of SEM images taken at the crack surface (Figure 7 (d)). The initial crack and the direction of crack propagation as shown in Figure 7 (a), then crack propagation occurred (Figure 7 (b)), until the end final fracture occurred as shown in Figure 7 (c).

3.3. Analytical Analysis

Analytical analysis aims to obtain the stress and the stress intensity factor value that appear due to the applied load working on the spring. The amount of force received by each suspension both front and rear is the total force divided by four wheels. For this purpose, 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 (*W*) is calculated using equation (1) [2][15].

$$W = \frac{m \times g}{4} \quad (N) \tag{1}$$

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 wheelsis 26950N.

Then the stress (**σ**) that occurs in the spring can be calculated using equation (2) [15].

$$\sigma = \frac{6\ x\ W\ x\ L}{n\ x\ b\ x\ t^2} \quad (MPa) \tag{2}$$

Where *W* is the load worked on each wheels of 26950N, *L* is half span of the spring is 430 mm, *n* is the total number of leaves 8 pieces, *b* is width of the leaves 70 mm, ***t*** is thickness of master leaf 14.5 mm. From the calculation results obtained that the stress that occurs in the spring is 590.55 MPa. It can be seen here that the stress that occurs exceeds the yield stress of the material (σ_y) as shown in Table 1. Therefore, it can be stated that the spring will fail due to deformed.

Furthermore, it will also be examined from the crack analysis by finding out how much the stress intensity factor (K_I) occurs in the spring due to the load received. Using a Single-edge-crack-at-hole specimen as shown in Figure 8, the value of K_I is can be calculated by means of equation (3) [16].

$$K_I = \sigma\sqrt{(\pi a) F_{hs}} \tag{3}$$

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Where a is the crack length. The crack length is obtained from the visual observation with the value is about 1.5 mm, $\boldsymbol{\sigma}$ is the stress that occurs in the spring as it found from equation (2). F_{hs} is the boundary-correction factor calculated referred to previous research methods [16]. Then, the results of boundary correction factor (F_{hs}) obtained of about 2.49. It was found that the K_I value occurred near the crack tip on the spring is about 63.95 MPa$\sqrt{m}$. This result shows that K_I is higher than the fracture toughness K_{IC} of AISI 5150 material equal to 23 MPa$\sqrt{m}$ (Table 2). Therefore, this can cause crack propagation occurred [11][13][15] as well as this fact indicates that this is one of the causes of leaf spring failure.

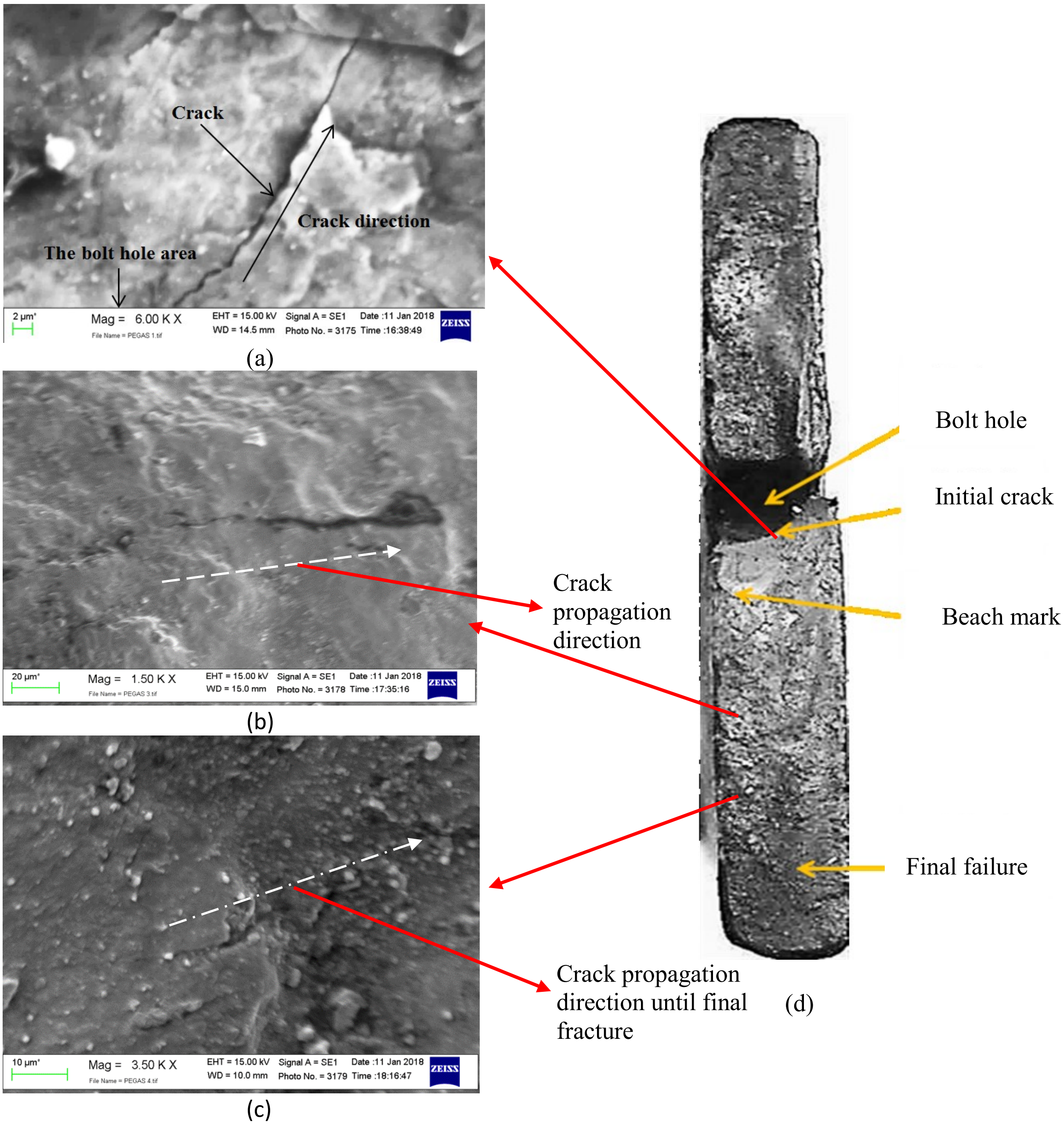

Figure 7. A series of SEM images taken at the crack surface. (a) The initial crack and the direction of crack propagation. (b) Crack propagation occurred. (c) Final fracture occurred. (d) Leaf spring fracture surface.

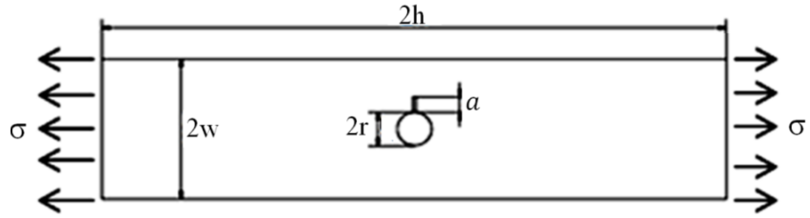

Figure 8. Configurations of Single-edge-crack-at-hole specimen (radius, r = 5 mm, width of the leaves, w = 25 mm).

4. Conclusions

Study on the leaf spring fracture behavior used in the suspension systems in the Diesel Truck vehicles has been studied and can be drawn several conclusions as follows:

1. From SEM observation, it was found that on the fracture surface of the spring identified the initial crack occur around the bolt hole. The crack extension starts on the bolt part then propagate to the cross section of the spring until final failure.
2. The value of stress intensity factor K_I is higher than the value of fracture toughness K_{IC} of AISI 5150 material. This result indicated that crack propagation occurred and this fact also indicated that this is one of the causes of leaf spring failure.
3. Fracture of the spring was also induced by fatigue fracture that characterized by existing the beach mark on the fracture surface.

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