Study of Failure Analysis of a Fracture Crankshaft Pulley Used on a Truck Engine

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Abstract. A pulley is a mechanism consisting of a wheel, with a groove between its two edges, which is fastened to a shaft. The belt usually passes along the groove of the pulley to give it the power of movement and rotation. In December 2016 there was a case of failure of the crankshaft pulley in a truck. This study aims to investigate the causes of fracture. Therefore, it was necessary to perform a failure analysis. Investigation methods included visual examination, scanning electron microscope analysis, chemical analysis of the material and mechanical tests. A finite element analysis (FEA) was also performed to quantify the stress intensity factor (K_I) distribution in the crankshaft pulley that is near the crack tip. From the finite element analysis, it was found that K_I was greater than the fracture toughness (K_{IC}) of the material. Therefore, the propagation of crack occurs from the initial crack until final failure.

1. Introduction

The failure analysis has always been a source of interest for the technical and scientific community as a way through to collection and analysis of data, determine the cause and prevent mechanical failure [1]. Mechanical failure can thus be defined as any change in size, shape of a structure, machine part that renders it incapable of satisfactorily performing his intended function [2]. Generally, failure to a product still occurs frequently due to incidents and other factors [3]. Many causes of fracture failure in a pulley in a truck are related with fatigue and fracture, improper fastening of support [4] or high stresses, friction and fretting [5]. Some methodologies to prevent the fracture failure of crankshaft pulley implies a better knowledge of mechanical design [6], stress concentration factors [7] and crack initiation and propagation mechanisms [8]. Failures due to incidents usually occur because of loads that exceed the strength of a component, for example, shock loads due to collisions, overloads, mixed loads between tensile loads and bending loads [9, 10]. Moreover, many automotive components can be associated with failure due to fatigue during their operations [11].

The crankshaft pulley of a truck was damaged on 20 October 2016. Therefore, this condition caused the engine of the truck to malfunction. Consequently, it is clear that cracks are a serious problem, and efforts must be made to overcome and prevent crack propagation [12, 13]. Furthermore, the purpose of this study was to investigate the causes of failure in a crankshaft pulley.

2. Methodology

Pulley is made of AISI 1045 material (table 1) as will be explained further in section 3.2. The engine component that was used was the crankshaft pulley of a truck. The pulley was located on the engine, as shown in figure 1 [14].
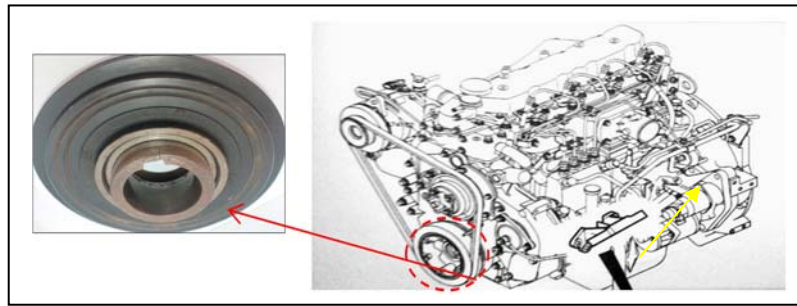
Figure 1. The engine components of the crankshaft pulleys.

To determine the shape, appearance, and location of the component that experienced macro failure were investigated by visual observations . The macroscopic observations were carried out on the component as shown in figure 1.

The identification of the chemical composition is carried out using optical emission spectroscopy (OES) to determine what chemical elements were quantitatively present in the crankshaft. The instrument used in this experiment was the PDA-700 spectrometer. Moreover, the fracture surface was observed by means of a scanning electron microscope (SEM) [15]. Hereafter, the testing of hardness with the Rockwell B method (with a loading of 100 Kgf) is aimed at determining the hardness of a material by means its resistance to specimens in the form of steel balls or diamond cones, which are exerted on the surface of the test material [16].

A *Stress Intensity Factor (K_I)* analysis *using the finite element method (FEM)* was used to determine the operating conditions of the component. The maximum stress intensity factor (K_I) was used to determine whether the cracks in the crankshaft pulley had propagated or not.

3. Results and Discussion

3.1. Visual Observations
The visual observations of the failure in the crankshaft pulley in figure 2 show the initial location of the cracks, and cracks in the visible area of the keyway. Then, figure 3 shows the surface fractures that occurred when the cracks began to appear in the parts. In this case, the area of stress concentration in the pulley was at the keyway because this was the area with the smallest radius and sharp angles.

3.2. Chemical Composition
The results of *chemical composition* **test** indicated that the crankshaft pulley material met the standard of the AISI 1045, as shown in table 1. The standard of the AISI 1045 [16] with regard to mechanical properties can be seen in table 2. The fracture toughness, K_{IC} had a value of 41 MPa$\sqrt{}$m [17].
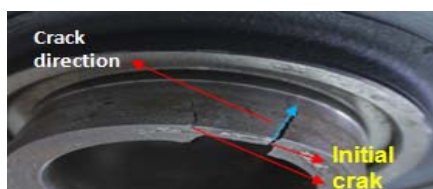
Figure 2. Initial crack on the crankshaft pulley.

Figure 3. Fracture surface.

3.3. Fracture Surface Observation Results Using SEM
The next stage, after the visual observations, was a fractographic examination using a Digital SLR camera. The results obtained were finally able to show the fracture surface pattern of the pulley. The observations this time, using a Digital SLR camera, referred to the predictions at the time of the visual observations, namely the crack initiation area, crack propagation, and also the final fracture. Then, to

find out more about the pattern that occurred in the initial area of the fault, observations were made at a magnification of 41x. The results can be seen in figure 4 (c), which shows the initial cracks that occurred and the propagation of the cracks in two directions, namely, upwards and sideways. There were also chevron lines in the image.

Table 1. Comparison of results of chemical composition testing and AISI 1045.

Type	Composition (wt %)				
	Fe	C	Mn	S	P
The test results using Spectroscopy	89.8	0.45	0.773	0.0336	0.201
AISI 1045	98.4	0.43-0.5	0.60-0.90	0.04 (max.)	0.05 (max.)

Table 2. Mechanical properties of AISI 1045 [16].

| No	Properties	Value	
1	Tensile strength (σ_B)	585	MPa
2	Poisons Ratio (υ)	0.29	
3	Yield strength (σ_{ys})	450	MPa
4	Young's Modulus, E	200	GPa
5	Hardness, Rockwell B	84	HRB
6	Density, ρ	7.87	Kg/m^3
7	Shear modulus (μ)	80	GPa
8	Shear Stress (τ_a)	146	MPa
9	Fracture Toughness, K_{IC}	41	MPa.m$^{1/2}$
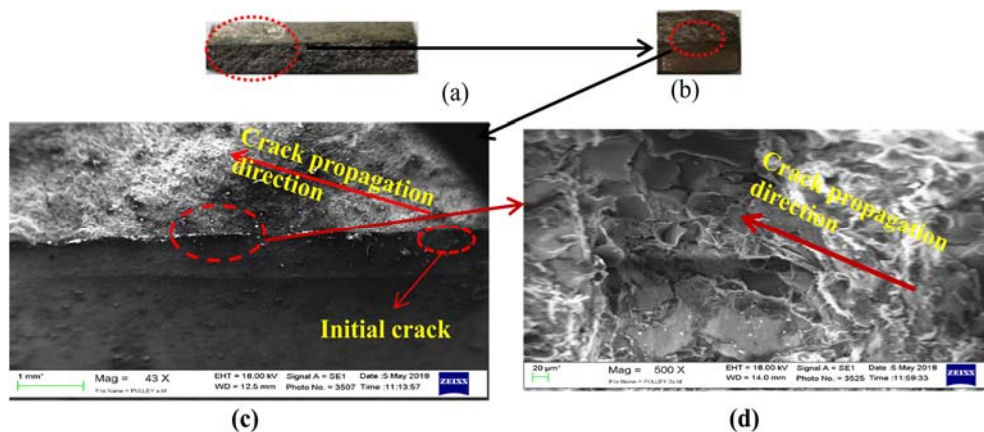
Figure 4. (a) Cut Part of the Pulley for SEM observation. (b) Specimens for Fractographic testing. (c) Initial crack location. (d) Initial Cracks Performed 500X Magnification.

Then, the next area to be observed was at the tip of the fracture surface area. For these observations to be made, a magnification of 43x was sufficient as it was clear that there was a fracture surface pattern in this area, as shown in figure 5.

3.4. Hardness Test Results
In a failure analysis research, it was necessary to test the hardness of the pulley pieces that failed, as shown in figure 6. Tests carried out using the Rockwell B hardness test equipment. The hardness test curve of the crankshaft pulley resulted from 9 hardness testing points using a load of 100 kgf.
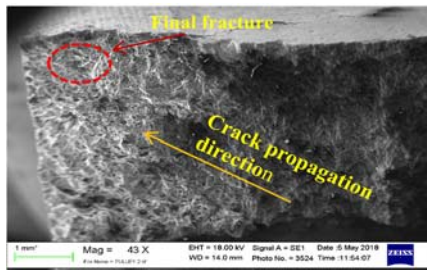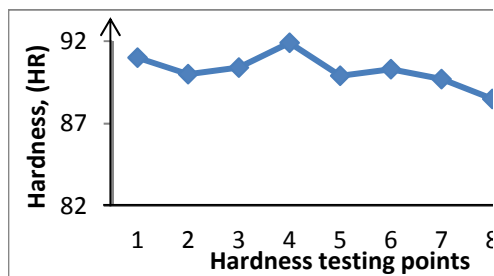
Figure 5. Fracture surface pattern.
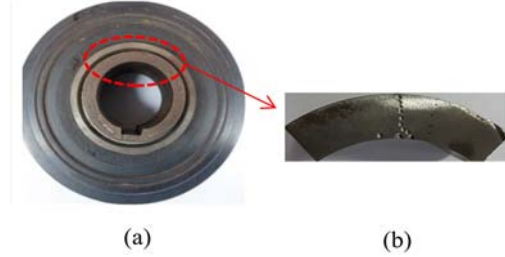
Figure 6. a) Parts of Pulleys Cut for hardness testing. b) Hardness Testing Specimen.

From the data obtained through the hardness test, as shown in figure 7 the average value of the hardness of the perpendicular cross-section was 88.6 HRB. The hardness of the inner area of the pulley was lower than that of the outer area of the pulley.


Figure 7. Hardness Testing Curve.
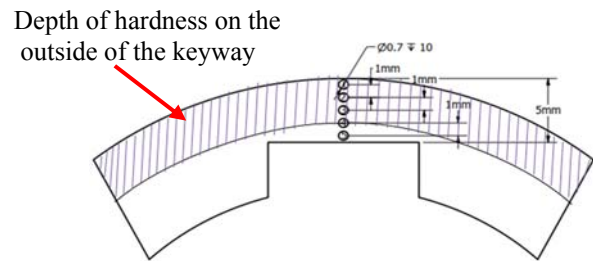
Figure 8. Sketch the hardness testing point around the keyway.

Figure 8 shows the keyway section, where the tightly-shaded part of the material with a thickness of 4 mm was harder than the part that was not shaded, while the remaining thickness of about 1 mm had a lower material strength than the shaded part, and it was this weaker part that caused the crack.

*3.5. Stress Intensity Factor (SIF) Analysis Using the Finite Element Method*
The results of the FEA on the crankshaft pulley showed the conditions that existed when a torsion moment force of 339876.9 N.mm was exerted. The geometry of the crankshaft pulley was made using software as can be seen in figures. 9(a), and (b)). Furthermore, a crack was made on the crankshaft pulley as shown in figure 10 so that simulations could be carried out to find the stress intensity factor (K_I) [18-20]. figure 10(a) shows the geometry of the crank axle and the given crack in the area of the groove, while figure 10(b) shows the enlargement of the crack area. The crack that was made had both a width and depth of 1 mm.
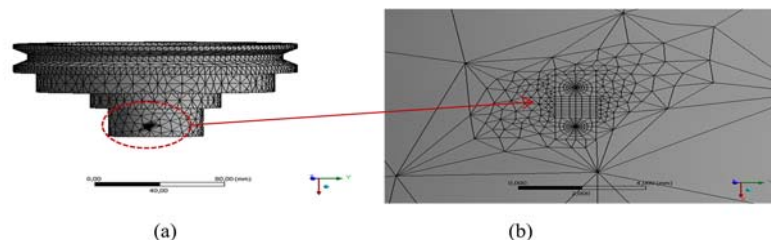
Figure 9. Geometry Crankshaft Pulleys after meshing.

The finite element analysis to find the stress intensity factor (K_I) near the crack tip on the crankshaft pulley by modelling the crack length and depth of 1.0 mm in the keyway area is shown in

figure 9. A stress intensity factor (K_I) of 88 MPa.$m^{1/2}$ was obtained from the simulation results larger than the fracture toughness (K_{IC}) of the material was about 41 MPa.$m^{1/2}$ (as shown in table 2) . Therefore, this result indicated that crack propagation occurred on the crankshaft pulleys until final failure.
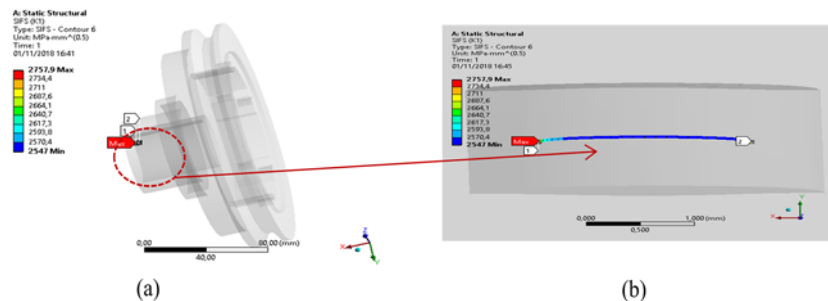
Figure 10. (a) Analysys of SIF (K_I). (b) Magnification around crack tip.

4. Conclusions

According to the results, it can be concluded that the initial crack occurred because of the stress concentration in the sharp-angled keyway. Moreover, from the FEA results K_I that occurred near the crack tip was greater than the fracture touhness, K_{IC}. This also caused the crack propagation in the groove of the crankshaft pulley.

Acknowledgement

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