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Failure analysis of the fracture surface of the crankshaft of a vehicle

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Abstract. The purpose of this study was to determine the cause of a fracture in the crankshaft of a 1000 cc gasoline engine. On the broken surface, it could be seen that the cracks started from the direction of the oil hole. A visual examination revealed that there were beach marks on the surface of the fracture, which is usually common in fatigue failure due to a dynamic load. From the test for the chemical composition, it was found that the material was classified as alloy steel. The Rockwell-based material hardness values were different. The highest hardness value of 102.2 HR_B was on the outer shell portion of the crankshaft on the *x* and *y* axes at points 1 and 14. Finally, it was concluded that the reason for the fracture in the crankshaft was fatigue failure, the material hardness that did not match that of the standard, as well as the initial crack contained within the radius of crank pin number 1.

1. Introduction
The crankshaft, which is one of the main components of a piston engine, serves to forward the rotation of the connecting rod to the clutch. In turbo diesel engines, it can be observed that the increase in engine power usually leads to a decrease in the life of the engine components [1]. Cracks generally start from the initial cracks that usually occurs on the surface of a weak material or in stress concentration areas, such as scratches, holes and others resulting from repeated loading. This initial crack develops into a micro crack or propagation that forms a macro crack, thereby culminating in failure [2]. Failure is a condition that is never desired because it causes direct losses. Failures are usually caused by design errors, material defects, and maintenance errors [3].

Failure analysis is a process for determining the factors that cause a component to losing its function. Failure analyses have been performed on crankshafts in several studies, such as by Witek [4]. In the study, failure occurred on crank pin number 2 after traveling a distance of 260,000 km. In 2016, Fonte [5] found that failure occurred on crank pin number 3 after three years and 5000 hours of maintenance. Figure 1 shows the crankshaft parts.

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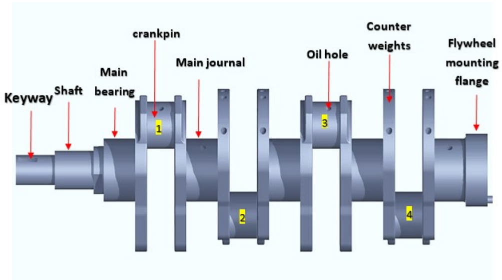

Figure 1. Part of a crankshaft.

Many researchers have concluded that most of the fatigue failures in crankshafts are due to dynamic loading [6-9]. Mistakes, both during disassembly and maintenance, should be avoided to prevent failure of the crankshaft. Scratches, for example, will cause an initial flaw that will lead to failure. Failure usually starts from a critical point experiencing a high stress concentration, such as within the area of the radius, and in errors while mounting the crank pin [6]. Therefore, the purpose of this study was to determine the cause of fracture in a crankshaft.

2. Methodology

In this study, the material used was taken from the crankshaft of a car. First, observations were made to determine the mechanical properties of the material. The visual inspection showed a crack on the crankshaft with an engine rotation speed of 5500 RPM. The crankshaft was broken at crank pin number 1, as shown in figure 2. The visual inspection showed beach marks on the fault surface, as shown in Figure 3, characterizing the cause of the failure.

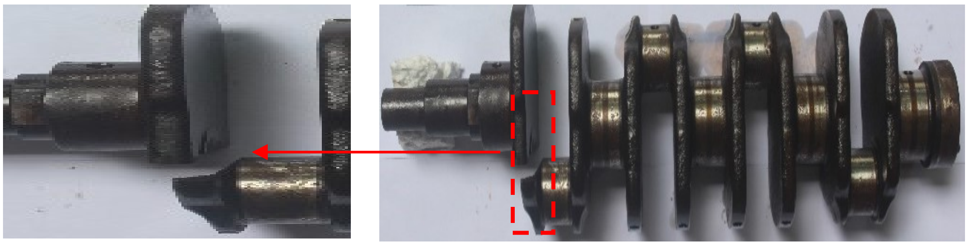

Figure 2. Failure of the crankshaft.

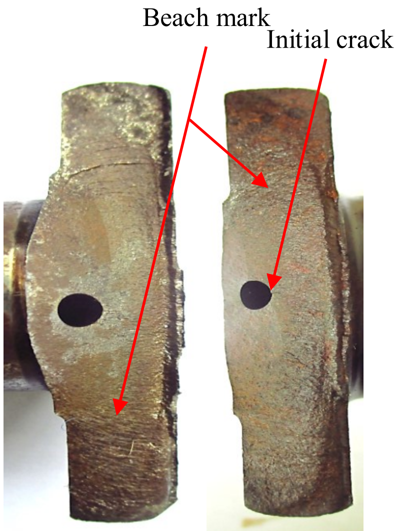

Figure 3. Failure surface of the crankshaft.

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Furthermore, the chemical composition was examined using a PDA-700 spectrometer to determine the elements contained in the material. Then, a hardness test was performed using a Rockwell Type Zwick / Roell ZHR to determine the hardness of the material with reference to the ISO 6568 and ASTM 18 standards with a load of 100 Kgf at the time of testing [10]. The experiments were performed on fourteen different points using a 1/16 indenter ball. Figure 4 shows a sketch of the specimen undergoing the hardness testing. A microstructural test was also performed using the Olympus GX 71 optical microscope with a magnification of 5 to 100 times, to view micro-sized objects and to determine the grain boundaries and the properties of the crankshaft material. Finally, scanning electron microscopy (SEM) was performed to view the broken surface on the crankshaft. The experimental test was necessary to determine whether the initial crack that had occurred on the crankshaft resulting in failure.

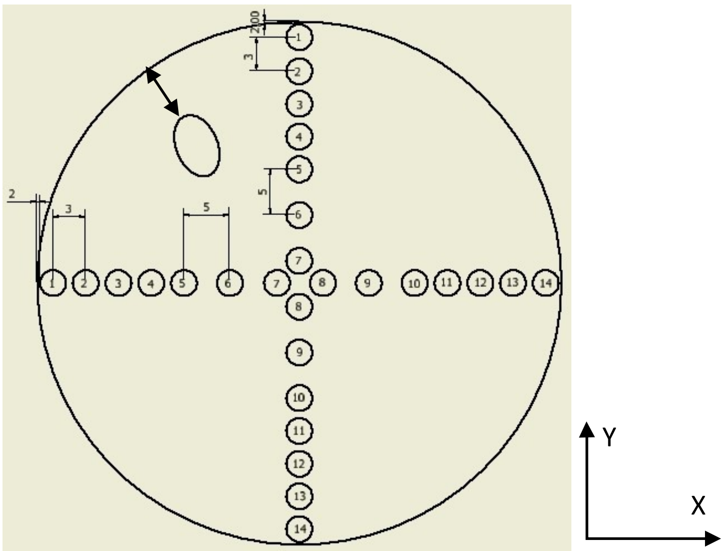

Figure 4. Hardness testing point.

3. Results and discussion

3.1. Chemical composition

From the chemical composition examination results, it could be concluded that the material was alloy steel, as shown in Table 1. According to ASTM A510 [11], the material used was AISI 1060, where the material properties can be seen in Table 2.

Table 1. Chemical composition of the material

Element	Spectroscopy results (%)	Chemical composition (AISI 1060) %
C	0,575	0,55 – 0.660
Mn	0,628	0.60 – 0.90
P	0,008	0.40 Max
S	0,025	0.050 Max

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Table 2. Material properties of AISI 1060 (ASTM A510)

Properties	Metric	Unit
Tensile strength (σ_B)	620	MPa
Posion Ratio (V)	0.30	-
Density (ρ)	7850	Kg/m^3
Yield strength (σ_{ys})	485	MPa
Modulus young (E)	200	GPa
Shear modulus (S)	80	GPa
Hardness, Rockwell B	89	HR_B
Fracture Toughness	36-60	MPa√m

3.2. Hardness test

From the hardness test results, it was found that the highest hardness value of 102.2 HR_B was on the outer shell portion of the crankshaft on the *x* and *y* axes at points 1 and 14. The hardness testing point can be seen in Figure 5. The hardness of the shaft on the outer shell was greater than at the centre to avoid defects and rapid wear during work. The hardness reached 13 mm from the outer surface of the crankshaft. Due to the unsuitable heat treatment process, the crankshaft was harder than the standard AISI 1060 material, which was 94 HR_B, while the average hardness of the crankshaft material that was tested was 100,83 HR_B. Therefore, the crankshaft, which was too hard to overheat up to a depth 13 mm from the outer surface, was prone to failure.

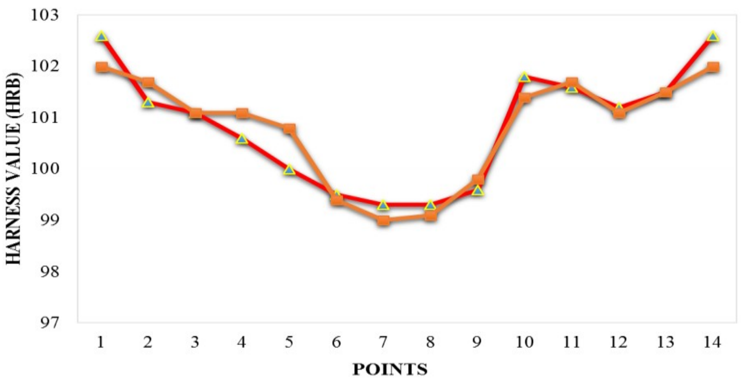

Figure 5. Graph of the hardness values (red is *x*-axis and orange is *y*-axis).

3.3. Observation of SEM

From the SEM test result, a defect around the oil hole was seen at a magnification of 3000 times using an EVO MA10 SEM. Due to maintenance errors and negligence in the installation process, there was a scratch with a sharp object resulting in the defect. The defect can be seen in Figure 6.

After observation of the factography by SEM, the existence of a crack was discovered. The result of a simulation using the finite element analysis revealed that the stress intensity factor was 2.42 MPa √m, which was smaller than the fracture toughness of 50 MPa√m of the material. Therefore, it could be concluded that the crack here did not spread. However, the crankshaft experienced fatigue failure here, as characterized by the beach marks on the crack surface of the crankshaft, as shown in Figure 3 [12]. Another cause was the material hardness that was up to a depth of 13 mm from the outer surface of the crankshaft. As such, the crankshaft was too hard and prone to fracture.

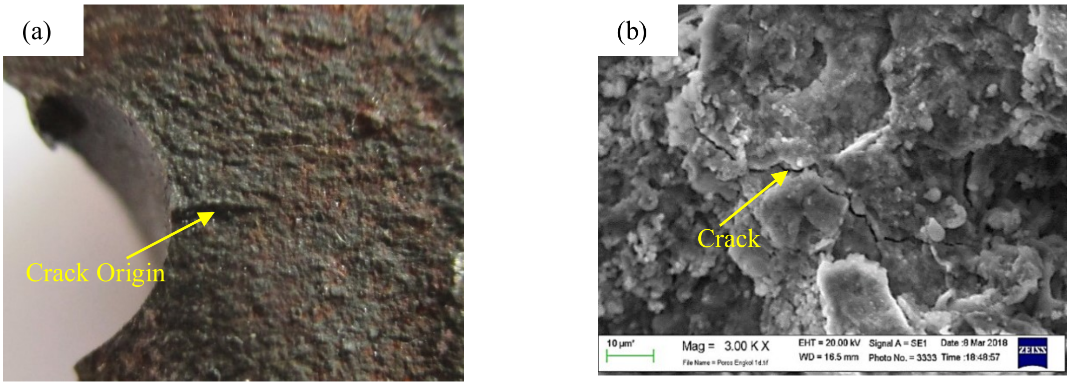

Figure 6. (a) Visual observation results and (b) result of the observation of the broken surface at a magnification of 3000 times.

3.4. Microsctructure

The results of the microstructural test revealed that the matrix was ferrite and pearlite [13] with a mean hardness value of 100.83 HR_B on the *x*-axis and 100.85 HR_B on the *y*-axis. This showed that this material was hypereutectoid steel, which is steel with a carbon content of between 0.02-0.76%. Figure 7 shows the results of the microstructural test with magnifications of 20 and 50 times.

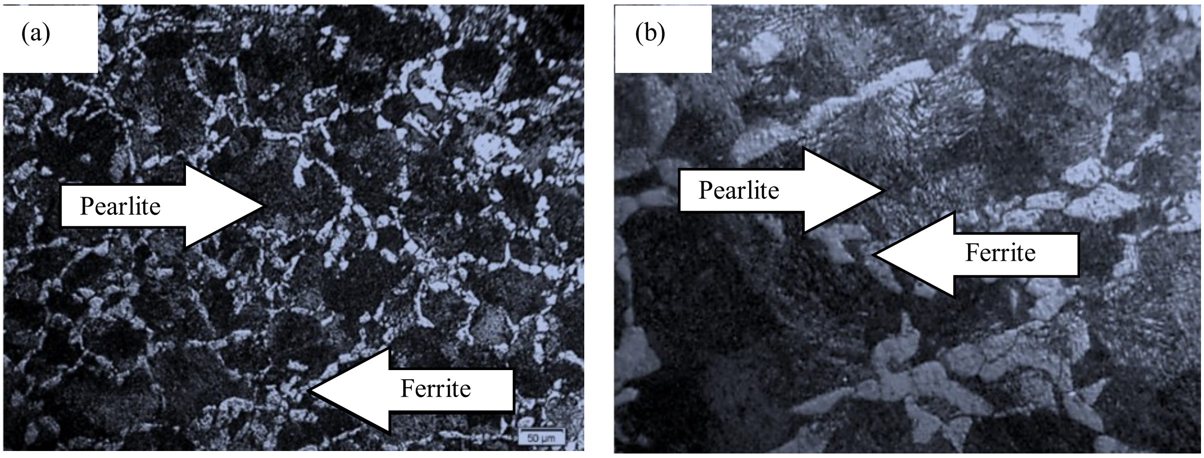

Figure 7. (a) Results of microstructural testing with 50x magnification and (b) results of microstructural testing with 20x magnification.

4. Conclusion

From the results, it was concluded that there were cracks on crank pin number 1 surrounding the oil hole. Over time, the cracks would be enlarged as the crankshaft continued to operate with spin and failure. Based on the simulation results, it could be seen that the maximum stress and strain were on crank pin number 1 due to a defect caused by the occurrence of scratches or the falling of sharp objects when the crankshaft was being installed on the machine.

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