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Analysis of the Crankshaft Failure of Wheel Loader Diesel Engine

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A B S T R A C T

The main purpose of this study is to review the cause for the crankshaft failure of six-cylinder diesel engine of a wheel loader after passing a short period of time. The failure had occurred after 4800 hours of in-service in the fifth crankpin of the crankshaft. Hardness and tensile tests were carried out to study their mechanical properties. Spectrophotometer machine was used to examine the chemical composition of the crankshaft material. To examine the material microstructure, its defects and the morphology of fracture surface, optical microscopes (OM) and scanning electronic microscopes (SEM) equipped with energy dispersive spectrometry (EDS) were used. The morphology of fracture surface showed that the fracture is of the smooth type and has occurred due to the fatigue. Main origin of the fatigue cracks appeared on the surface of the crankpin might be created by the existence of oil impurities, the impurities on the surface of the crankpin, inappropriate machining on the surface of the crankpin or severe wear and pitting from insufficient lubricating.

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1. INTRODUCTION

The analysis of failure is a regular investigative technique using scientific methods to identify the causes of failure. The analysis of failure is an integral section of designing and manufacturing process. Figure 1 shows that failure investigation has a reverse relationship with designing process [1].

Figure 1. Failure analysis is the reverse of the design process [1]

The parts of engine and the power transmission system of most road construction machineries and their equipment are exposed to various kinds of cyclic stresses and harsh environmental conditions. Wheel loader is a machine of heavy equipment that is used in construction for moving, lifting different materials onto other machines such as dump trucks, conveyors and railroad cars. This machine can also carry out tasks such as leveling by soil spreading, digging of soil, dumping loaded bucket, loading dump truck and hauling materials [2].

One of the main rotating parts of the engine is crankshaft. The individual components of the crankshaft have been shown in the broken crankshaft of Figure 2. Crankshaft in the internal combustion engines is a shaft that turns the linear motion of piston into a rotational motion through connecting rod.

The analysis of the crankshaft failure was studied in Refs [3-7]. The studies show that the most failures occur in crankpin-web fillet region with high concentration stress caused by the effect of fracture mode I under

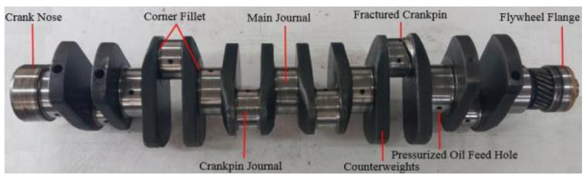

Figure 2. Engine crankshaft terminology.

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alternating rotational bending load. Other factors which affect the fatigue life include: (1) high vibrations due to crankshaft imbalance or lack of balancer; (2) lack of enough oil between the bearings and the main journal or crankpin; (3) high pressure caused by combustion in the cylinder; and (4) the emergence of the cracks made during the manufacture especially between the crankpin-web fillet regions [8-12]. Besides, there are other factors that cause the failure of the crankshaft or shaft such as the pieces taken apart from the screws or pins due to the high stress concentration or inappropriate assembly of the parts attached to them which are exposed to rotational bending fatigue loads. The fracture of the parts causes the crankshaft failure or shaft failure and other parts connected to both [13, 14]. Shaft failure might be due to the load of rotational bending fatigue which in turn caused by the tiny cracks on the shaft and close to the keyway area while doing installation, operation, or maintenance [15].

The main goal of this paper is to study the reasons for the crankshaft failure in six-cylinder diesel engine of the wheel loader after passing a short period of time. To examine the causes of the failure the results of some cases were used including chemical composition and microstructure of the crankshaft material, mechanical properties tests, SEM images of the fracture surface. The morphology of the fracture surface showed that the fracture is of the smooth type and it is caused by the fatigue.

2. THE METHOD OF THE REVIEW OF EXPERIMENTAL WORK

The review method of crankshaft failure of six-cylinder diesel engine of a wheel loader has been carried out as follows:

1. Choosing the broken crankshaft of a wheel loader.
2. Measuring the dimensions and analyzing broken crankshaft photographs.
3. Analyzing of the chemical composition of the crankshaft material.
4. Testing the mechanical properties including hardness and tensile.
5. Examining the material microstructure using OM.
6. Photographing and observing the fracture surface using SEM.
7. Investigating the causes for failure.

The above-mentioned topics will be dealt with in the following parts.

3. THE RESULTS AND ANALYSES

This case study is about examining the crankshaft failure of six-cylinder diesel engine of wheel loader. The measurements of the damaged crankshaft of six-cylinder diesel engine of wheel loader were measured with high precision micrometer, vernier-caliper and digital scale and have been listed in Table 1.

3. 1. Mechanical Properties of the Material of the Crankshaft

The chemical composition of the material of crankshaft was carried out following the ASTM E41 standard using the spectrophotometer model SPECTROMAX made in Germany. The tests were carried out in 24 degrees Celsius and the humidity was 23%. The tests were repeated 3 times. The results of the average mean of the numbers based on the weight percentage have been given in Table 2.

To study the mechanical properties of the material of crankshaft, two samples were made based on ASTM E8M-97a standard and the ones mentioned in literature [16]. This standard specifies the method of the tensile of metal materials. A typical sample is shown in Figure 3. This ended up to putting the samples under tensile by Zwick/Roell model Z100/Z250 materials testing machine with central ball-lead screw having the capacity of 25 tons.

TABLE 1. Crankshaft specifications and conditions.

Crankshaft Parameter	Specification
Crankshaft mass	102 Kg
Crankshaft length	1052 mm
Main journal diameters	100 mm
Crankpin diameters	82 mm
Operation	4800 hr

TABLE 2. The chemical composition of DIN1.7225 and Standard alloy.

Symbol	DIN1.7225	Standard
Fe	97	Base
C	0.414	0.38-0.43
Si	0.247	0.15-0.35
Mn	0.74	0.75-1.00
P	0.011	≤0.035
S	0.024	≤0.040
Cr	1.16	0.80-1.10
Mo	0.216	0.15-1.25

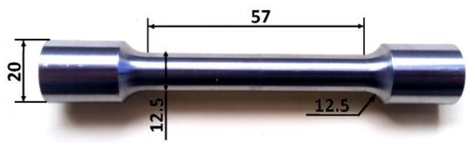

Figure 3. Geometric dimensions of test sample 12.5 mm

The results of the tests were recorded in the form of the force-displacement and the rate of sampling was 2 times per second. The length changes of the samples were measured by extensometer having the length-measurement of 50 millimeters. To carry out the tests, the moving speed of the machine gripes was 0.50 millimeter per minute. The ultimate stress, yield stress and elongation were measured using the results of the tests. The mechanical properties of the tested material in crankshaft have been given in the Table 3. The graphs of the strain-tension have been drawn in Figure 4. Based on the results of the analysis of chemical composition and the tensile tests, the mechanical properties of the crankshaft material follow the steel W.Nr. 1.7225 DIN 42CrMo4.

3. 2. Hardness and Optical Micrographs

At first, a cross-section of the broken crankshaft crankpin having the thickness 15 millimeters was sliced using the electro-discharge wire cutting. Then, the surface of the samples were sanded using the sanding papers No. 60 up to 1200. Polishing the samples was done by using the diamond paste. The micrograph of the crankpin cross-section of wheel loader was obtained. Then, the hardness measuring tests was done using Brinell criterion based on ASTM: E384-11e1 standard. To do the hardness tests, an Avery-denison tester was used and the tests were repeated 3 times. The hardness measuring test on the sample was done exerting 120 Kgf in 20 seconds and the hardness graph from the center to outside surface of the crankpin was drawn in Figure 5.

TABLE 3. Mechanical properties of the DIN1.7225 and Standard alloy.

σ_Y (MPa)	Symbol	Elong. (%)	σ_U (MPa)
Standard alloy	Min. 650	900-1100	Min. 12
Sample 1	647.65	823.92	18.34
Sample 2	671.25	832.3	17.9

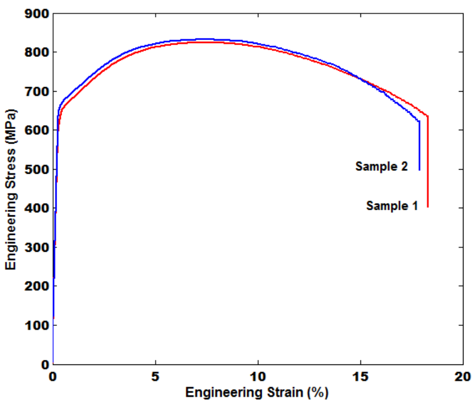

Figure 4. Engineering stress vs. engineering strain curves of crankshaft material

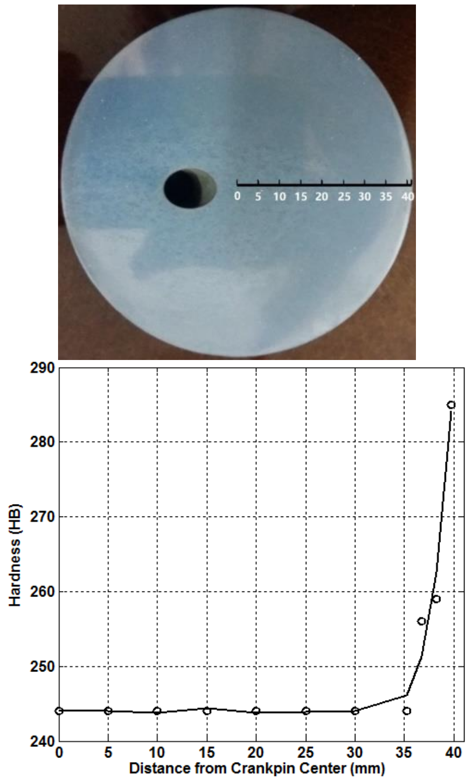

Figure 5. Hardness distribution from center to outer diameter of the crankpin.

The hardness increasing from the center of the crankpin to its surface is due to the faster cooling of the surface of the crankpin relative to the central regions, which causes the residual stress between the two surface and central regions. Therefore, one of the reasons for fatigue crack initiation is the lack of hardness uniformity between the surface and the center of the crankpin, which can be a factor in the fatigue crack initiation.

A cross-section microstructure of crankpin was observed using OM. Figure 6 shows the micrograph of the crankpin no. 5 after polishing with 1000x magnifications. The oxidized inclusions are found in great amounts on the polished areas. Figure 7 shows the micrograph after being etched. The tampered martensite structure was observed which hardness measuring approves the results.

3. 3. Examination of the Fracture Surface and the Cause of Failure

To study and examine the fracture surface of the crankpin, the sample was put in ultrasonic bath first, then the SEM machine made in Germany LEO 1450VP model was used for imaging. The EDS 7335 model made in Oxford England connected to this SEM machine could measure chemical composition. In this research, it is used for the instant chemical composition of the cracks, defects and impurities.

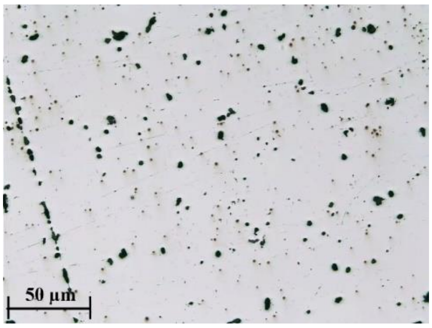

Figure 6. Micrograph of the material as polished with 500x magnifications

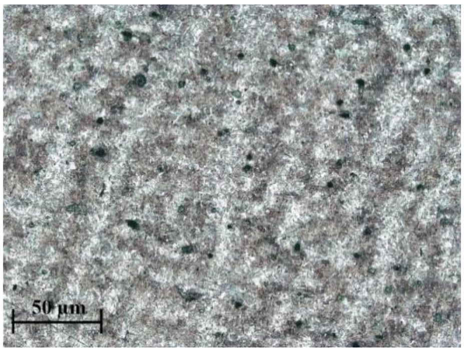

Figure 7. Micrograph of the material etched with 500x magnifications

Figure 8 shows the fracture zone of the broken crankpin of the wheel loader of the crankpin-web fillet root. This has happened after 4800 hours in-service. The morphology of the fracture surface shows that it is of a smooth type and it has been caused by the fatigue being affected by the rotational bending load. The fracture surface includes two zones: (1) the crack initiation and propagation zone with beach marks and ratchet marks; and (2) final fracture zone in front of the crack initiation zone. Figure 8.a shows the fatigue crack initiation position on the cross-section of the broken surface. Main origin of the fatigue cracks appeared on the surface of the crankpin might be created by the existence of oil impurities, inappropriate machining on the surface of the crankpin or severe wear and pitting from insufficient lubricating or it might be because of other impurities on the surface of crankpin as polished image shows it might be of oxidized inclusions type. The fact that the final fracture zone is near the surface, the stress put in the surface is so close the fatigue limit.

Comparing the fractured surface of Figure 8 with the schematic guidelines of Figure 9 on the fracture surface of the shafts [17, 18], the following specifications can be referred to: (1) high cycle; (2) low stress with the small zone of the final fracture compared to the wide cross-section of the whole crankpin due to the cyclic stress caused by rotational bending loads; and (3) a medium stress concentration.

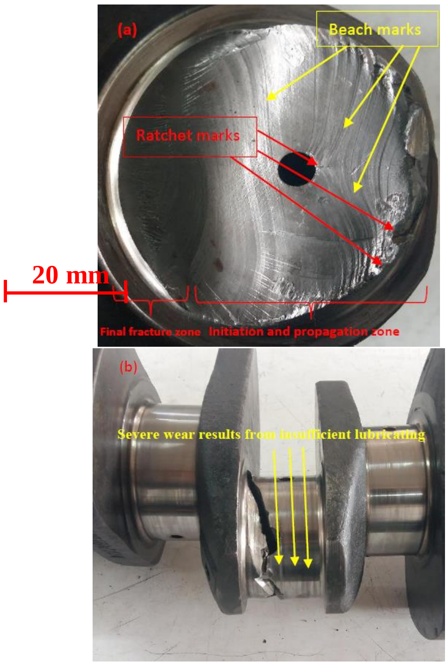

Figure 8. (a) Photograph of the failed crankshaft at the fifth crankpin; (b) The fractured surfaces of the crankshaft at the second crankpin

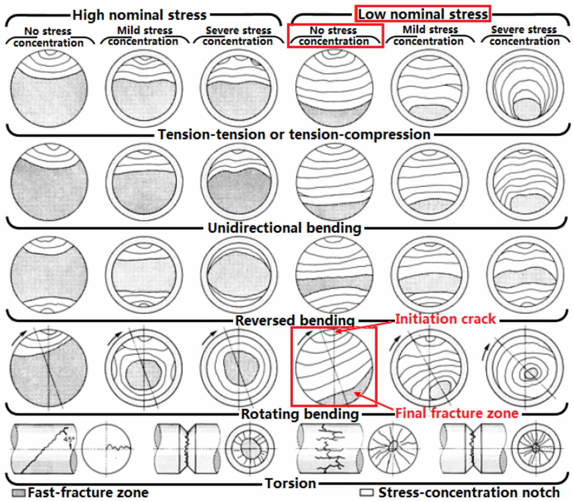

Figure 9. Schematic representation of fatigue fracture surface marks in shafts [18].

According to the crack initiation and propagation zone and the final fracture zone of the Figure 8, the amount of rotational load compared to bending load is negligible.

To examine the more precise origin of fracture of Figure 8, SEM images along with EDS with different magnifications were prepared. First the sample was put in ultrasonic bath and the Figures 10 and 11 were prepared. Figure 10 shows the incidence of striations, which are the marks of fatigue.

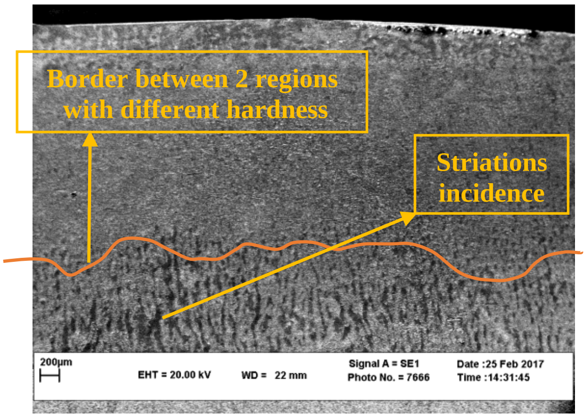

Figure 10. SEM micrograph of the fatigue marks with 70x magnifications.

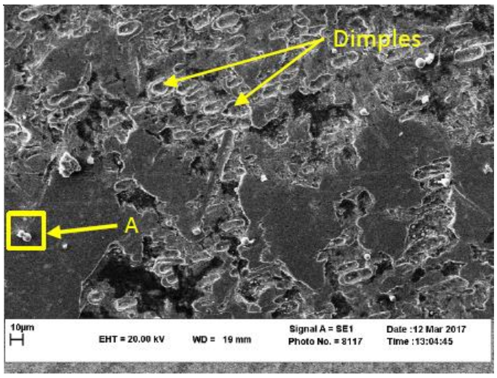

Figure 11. SEM micrograph of the crack after ultrasonic bath with 500x magnifications

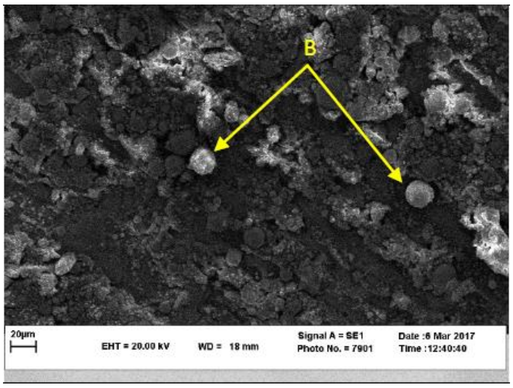

Figure 12. SEM micrographs of the crack before ultrasonic bath with 1000x magnifications

Figure 11 shows the fractography of SEM which is one of the features of the dimple fracture.

A series of particles such as A were observed on the fracture surface. The fact that the metal particles of A are seen on Figure 11 on the fractured surface, Figure 12 was prepared from the other side of the fractured surface of the crankpin without being put in the ultrasonic bath. The result was that metal particles of B was reappeared.

Then another photograph with 2000x magnification was taken and the EDS from the materials of square C was prepared (see Figure 13). This is not an impurity; but, it might be the remaining materials from the severe wear of the two sides of the broken crankpin while in-service or the cutting process for preparing of the sample by wire-cut machine. The similar particles of this research have been observed in the literature [19].

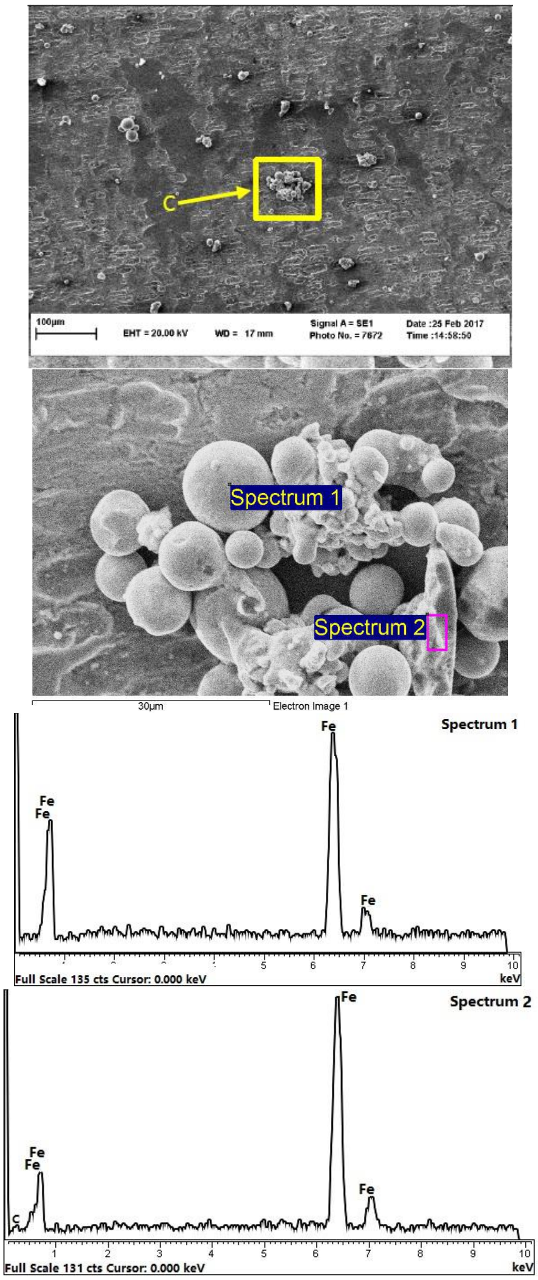

Figure 13. Micrographs of the crack after ultrasonic bath with 2000x magnifications.

4. CONCLUSIONS AND RECOMMENDATIONS

A review of the studies done on the examining the broken crankshaft of a six-cylinder diesel engine of a wheel loader was carried out. The failure of the crankshaft had happened after 4800 hours in-service on the fifth crankpin of the crankshaft. The examination done by using OM showed that the steel microstructure is of martensite type, showing the lots inclusions of on the cross-section of the polished crankpin. Micro-graphing crankpin no.5 after being etched showed that the few changes in the grain structure in the outer radius relative to the crankpin center are seen and the hardness diagram confirms this fact. SEM equipped with EDS was used to study the fracture surface and failure cause. The morphology of fracture surface showed that fracture is a smooth one and it has happened because of the fatigue caused mainly by the rotational bending loads. The fact that the final fracture zone is near the surface, the stress put in the surface is so close the fatigue limit. Due to the hardness results, surface hardness is more due to the more cooling rate than the central zones, which, of course, causes residual stresses between the two zones. SEM images also show the incidence of striations between two zones with different hardnesses. Therefore, in order to reduce the residual stresses, it is recommended that after forging crankshaft, stress relieving is carried out at a temperature of 500-550 ° C.

Also, the crack initiation zone is from the crankpin surface might be due to the following reasons: 1) the existence of oil impurities, 2) inappropriate machining on the surface of the crankpin, 3) severe wear and pitting from insufficient lubricating 4) other impurities on the surface of crankpin as polished image shows it might be of oxidized inclusions type.

In order to prevent the occurrence of such problems, it is recommended to change the oil within a specified period. It is also proposed to use better quality and reduced impurity steel as much as possible. Also, the quality of the machining surfaces must be checked to ensure that there won't be any rough and deep lines in the surface.

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The Analysis of Wheel Loader Diesel Engine Crankshaft Failure

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چکیده

هدف اصلی این مطالعه بررسی علت شکست میل لنگ موتور شش سیلندر دیزل لودر پس از مدت زمان کوتاه است. شکست پس از حدود 4800 ساعت در پنجمین محور لنگ از محل محور لنگ اتفاق افتاده بود. برای بررسی خواص مکانیکی تست‌های سختی و کشش انجام گرفت و از دستگاه اسپکتروفتومتر برای بررسی ترکیب شیمیایی عناصر تشکیل دهنده میل لنگ استفاده گردید. برای بررسی ریزساختار، عیوب، سطح شکست و علت شکست از میکروسکوپ‌های نوری و میکروسکوپ الکترونی روبشی (SEM) مجهز به طیف سنجی پراش انرژی پرتو ایکس (EDS) استفاده شدند. مورفولوژی سطح شکست نشان داد شکست از نوع نرم و در اثر خستگی روی داده است. محل شروع ترک خستگی از سطح قطعه می‌باشد که عامل آن می‌تواند حضور ناخالصی ناشی از روغن و یا ناخالصی در سطح محورلنگ، خطوط ناشی از ماشینکاری نامناسب روی سطح محورلنگ و یا سایش شدید و ایجاد حفره در اثر روانکاری نامناسب روی سطح باشد.

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