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Crack Analysis Of A Gasoline Engine Crankshaft

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ABSTRACT

In this study, failure analysis of a crankshaft was carried out. The crankshaft made of nodular graphite cast iron was used in a gasoline engine. The cracks propagated axially on surface of the 4th pin journal. Microscopic observation was conducted on the surface of journals. Mechanical and metallurgical properties of the crankshaft including chemical composition, micro-hardness, tensile properties and roughness were studied and compared with the specified properties of the crankshaft materials. As a result of the analyses, the main reason of failure was determined as thermal fatigue because of contact of journal and bearing surface. This condition leads to the formation and growth of fatigue cracks. The contact is probably resulted from defective lubrication or high operating oil temperature. In addition, the contact caused scratches on surface of the 4th pin journal and 5th main journal.

Keywords: *Crankshaft failure, Cracks, Thermal fatigue, Automotive failures*

1. INTRODUCTION

Crankshaft is one of the main components of internal combustion engines which convert reciprocating displacement of the piston to a rotary motion. A typical automotive crankshaft consist of main journals, connecting rod journals (crank-pins), counter weight, oil hole and a trust bearing journal. During the service life, combustion and inertia forces acting on the crankshaft cause two types of loading on the crankshaft structure; torsional load and bending load [1, 2].

Crankshafts are produced widely from forged steels and nodular cast irons. Forged steel crankshafts have less number of microstructural voids and defects compared to castings. In addition, the fatigue properties of forged steel crankshafts are usually better than that of cast irons. However, forged steel crankshafts have two important disadvantages; 1) higher cost due to higher production and machining costs, 2) higher weight due to the higher density of steel.

The properties of nodular and cast iron are similar to those of forged steels. This material has good fluidity and castability, excellent machinability, high toughness, good wear resistance and low cost [3, 4].

Crankshaft failures may be resulted from by several causes which are oil absence, defective lubrication on journals, high operating oil temperature, misalignments, improper journal bearings or improper clearance between journals and bearings, vibration, high stress concentrations, improper grinding, high surface roughness, and straightening operations [5]. The crankshaft faults caused high cost of maintenance in automotive industry.

In this study, a failed crankshaft reported by automotive service technicians was examined in order to determine causes of the failure. The crankshaft made of nodular graphite cast iron is used in an automobile with four cylinder 75 HP gasoline engine. General appearance of the crankshaft is seen in Figure 1. A main crack and micro-cracks were determined on the surface of 4th crank pin journal. The cracks propagated along surface of the journal in axial direction.

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Figure 1. General appearance of the failed crankshaft

2. EXPERIMENTAL METHODS

After the cleaning and visual examination, journals of the crankshaft were cut for failure analysis. The structure of the cracks was examined with microscopy. The chemical composition of the failed crankshaft material was determined with spectroscopy chemical analysis method with Thermo ARL 3460 test machine. In order to determined depth of hardened layer at crankpin and fillet region of the crankshaft journals, micro-hardness values were measured with Vickers hardness tester with a load of 500 g. The tensile properties of crankshaft materials were evaluated by tensile test with Shimadzu test machine. Tensile specimens were machined from centre of the crankpin portion. Dimensions of the specimens were a gauge diameter of 5 mm and a gauge length of 25 mm. Roughness of main and pin journals surface was measured with Hama TR100. The tests were conducted 3 times and the averages of the results were calculated.

3. RESULTS

From the visual examination, a crack was determined on the surface of 4^{th} pin journal which can be seen with naked eyes (Figure 2). The crack was called as main crack. The main crack propagated axially along the surface of the journal from one side to other. There were scratches on surface of the 4^{th} pin and 5^{th} main journals (Figure 3 and Figure 4). The scratches can be resulted from contact of bearings and journal surfaces. The observation of the journal surface with microscopy showed that there were micro-cracks at the near of the main crack which were parallel to the main crack (Figure 3 and Figure 4) and some of them connected with the main crack. As can be seen in Figure 5 and Figure 6, the micro-cracks dispersed and formed branches. Examination showed that the main crack and micro-cracks were superficial on surface of the journal. As can be seen in Figure 7, a good nodularity of graphite was observed in microstructure of the crankshaft material.

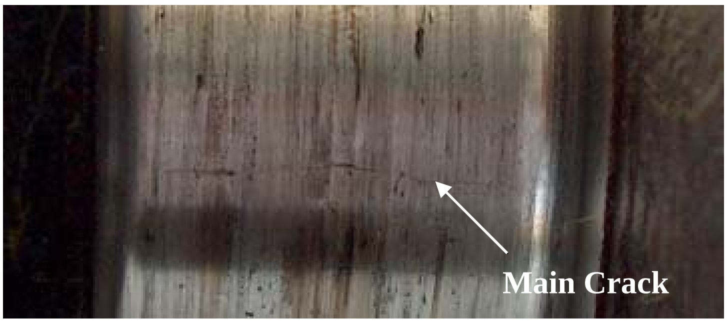

Figure 2. Magnified view of the main crack

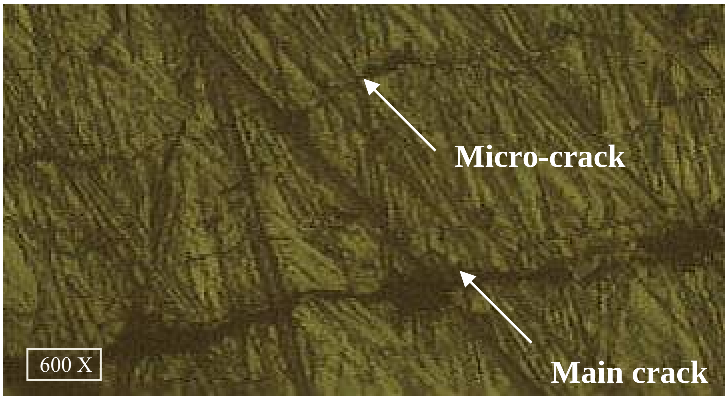

Figure 3. View of the main crack and a micro-crack

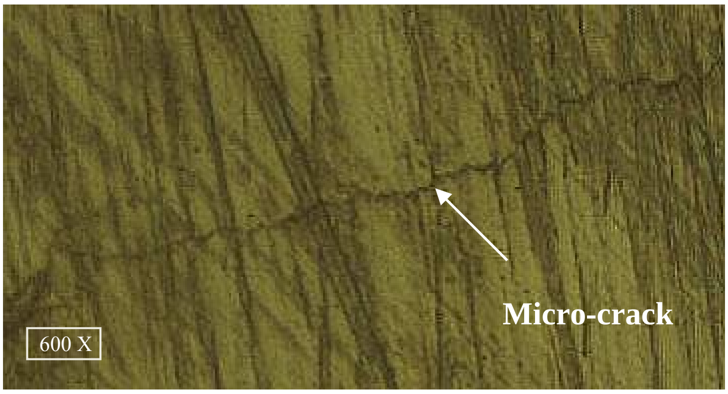

Figure 4. View of a micro-crack

Figure 5. Dispersion of a micro-crack

Figure 6. Formation of branch of a micro-crack

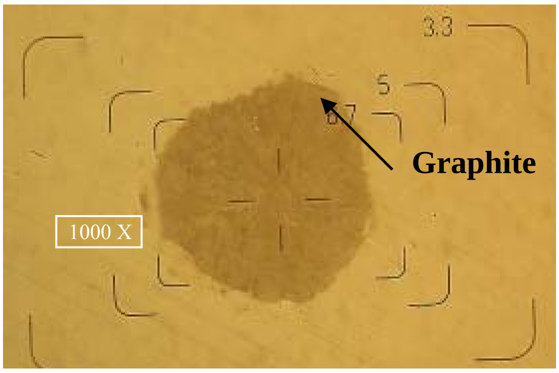

Figure 7. Microstructure of the failed crankshaft

The chemical composition of material of the failed crankshaft is given in Table 1. As can be seen, carbon content of the crankshaft was slightly higher than that of the technical specification. Higher carbon content increases the amount of graphite formation and decreases fatigue strength of crankshaft [6]. Other values were within the range of the technical specification.

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

Element (%)	**C**	**Si**	**Mn**	**S**	**P**	**Cr**	**Cu**	**Mg**
Analyzed	5.19	2.58	0.183	0.00418	0.0204	0.0312	0.793	0.0378
As specified	3.2-4.5	1.8-2.8	0.10-1.0	0.035 max	0.040 max	0.080-1.20	0.80-1.20	0.03-0.05

Variation of micro-hardness values of the crank pin and fillet region was shown in Figure 8. Micro-hardness was measured with a load of 500 g from surface to center with an interval of 0.5 mm. Depth of hardened surface was about 2.5 mm. As can be seen from Figure 8., lower hardness values were measured at fillet region compared with the crank pin. Micro-hardness of the crankshaft corresponds to the specified range.

Variation of the micro-hardness values on the surface of the crank pin starting from fillet region are given in Figure 9. Micro-hardness values measured with an interval of 0.5 mm. Micro-hardness values changed between 502 to 930 H_v.

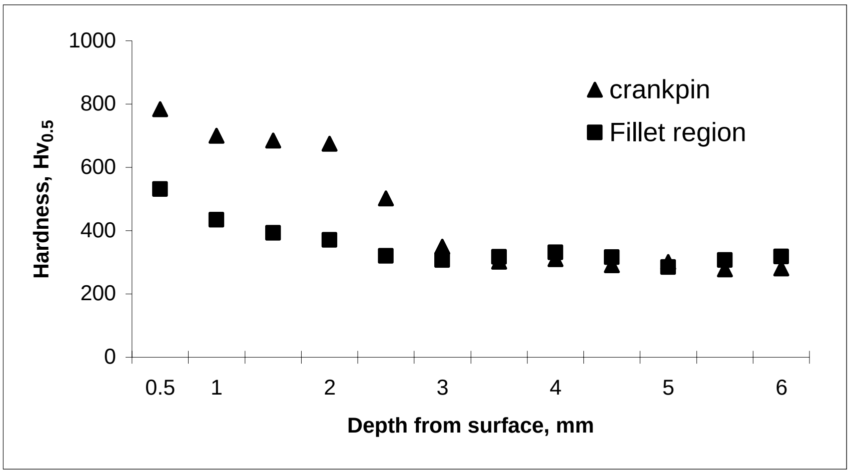

Figure 8. Micro-hardness profiles of the crankpin and fillet region

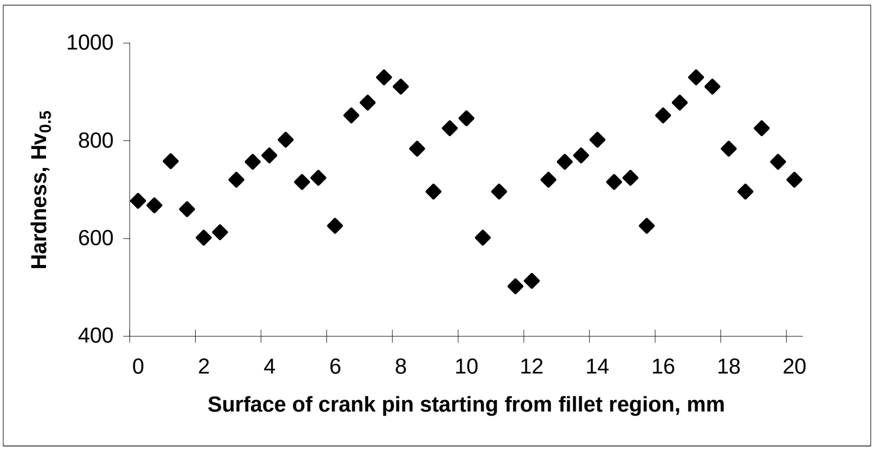

Figure 9. Micro-hardness profiles of the crankpin surface

Surface roughness of main and pin journals is given in Table 2. In comparison with other journals, higher roughness values were measured on the surface of 5^{th} main journal and 4^{th} pin journal. This was probably because of contact (friction) of the journals and bearings. Higher roughness is an undesirable property for journals, because it causes friction, wear, drag and fatigue.

Table 2. Roughness of main and pin journals

	1st main journal	2nd main journal	3rd main journal	4th main journal	5th main journal	1st pin journal	2nd pin journal	3rd pin journal	4th pin journal
Roughness (Ra)	0.24	0.23	0.26	0.25	0.56	0.26	0.19	0.25	0.87

Tensile properties of the crankshaft materials are shown in Table 3. It can be seen that the tensile properties of the crankshaft materials are within the specified range.

Table 3. Tensile properties

	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
Measured	485	860	4
As specified	>440	>800	>2

4. ANALYSIS OF RESULTS

Apart from slightly higher carbon content, metallurgical defects were not observed in the crankshaft material. However, the higher carbon content did not affect the mechanical properties of crankshaft material such as micro-hardness, tensile properties and roughness values which are within specified ranged.

As a result of the analyses, the main reason of the failure was thermal fatigue because of contact of journal and bearing surface. The contact can be resulted from two reasons which are lubricating problems (oil absence, defective lubrication on journals, high operating oil temperature), assembling problems (misalignments, improper journal bearings or improper clearance between journals and bearings). For the failure analysis, assembling problems can be eliminated because, before the crack problems, the automobile has been driven for long time (58 000 km). In addition, from the lubricating problems, oil absence was eliminated, because automotive service technicians reported that level of the engine oil was suitable during the first examination. Consequently, the cause of the contact of the journals and bearings can be defective lubrication or high operating oil temperature.

5. CONCLUSIONS

The following results were concluded from failure analysis of the crankshaft:

* Visual examination with naked eyes and microscopy showed that the main crack and micro-cracks propagated axially along surface of the 4th pin journal. In addition, there were scratches on surface of the 4th pin journal and 5th main journal.
* Carbon content of the crankshaft material was slightly higher than that of the technical specification. However, mechanical properties of the failed crankshaft such as micro-hardness, tensile properties and roughness values were within specified ranged.

* As a result of this experimental study, the cracks were resulted from thermal fatigue because of contact of journal and bearing surface. The contact can be resulted from defective lubrication or high operating oil temperature.

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