A. Y. JIAO, F. L. CHEN, B. H. LIU, J. W. DENG

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FAILURE ANALYSIS OF A DIESEL ENGINE CRANKSHAFT

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Preliminary Note – Prethodno priopćenje

In this paper, the macroscopic observation and chemical composition analysis of the third crankshaft journal have been carried out. Moreover, macroscopic observation, chemical composition analysis and metallographic analysis were carried out, and were compared with the journal with cracks and without cracks. Based on the experimental results and the causes of crankshaft neck cracks, it can be concluded that the crack form of crankshaft goes along with the grain brittle direction.

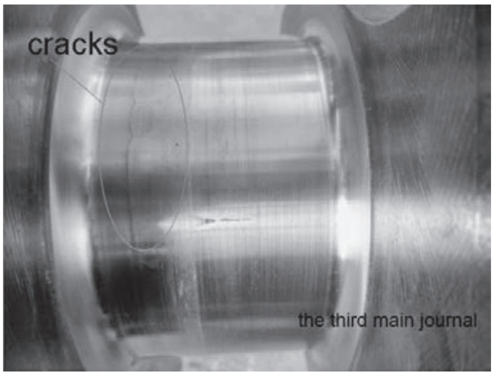
Keywords: 42CrMo; crankshaft; crack; metallography; hardness

INTRODUCTION

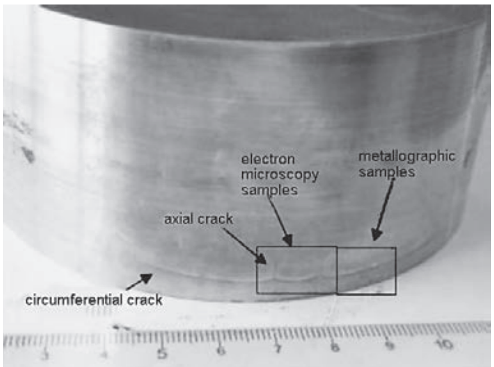
The heart of an engine vehicular is the crankshaft because vehicular movement would seize if it fails [1]. However, sometimes premature failure cases can also be reported [2,3]. In general, the causes of failure of the crankshaft are due to the result of a combination of many factors [4,5].

This study has presented the results of a microstructural and fractographic study on the failure of a diesel engine crankshaft [6]. The premature breakage of a diesel engine (350 kW) crankshaft had once been reported in a truck plant. After the engine turned on, the test started and abnormal noise appeared obviously. After the engine stoped and disassembled, cracks were found at the third main journal of the crankshaft which can be observed by eye. The crankshaft was made of 42CrMo forging steel with a 4-cylinder diesel engine which was used in a truck.

Process in crankshaft production: bloom → forging shape → trimming → quenching → tempering → machining → mechanically grinding → surface flaw detection (magnetic particle) → finishing → product. This paper describes a detailed metallurgical investigation on the failed crankshaft and demonstrates a careful fractographic study. The cause of the failure may be due to taken precautions when manufacturing the crankshaft [7].



(a) The third crank journal



(b) Distribution of cracks

Figure 1 Macroscopic morphology of crankshaft journal with cracks

EXPERIMENT ANALYSIS

Macroscopic State

Many defects can be found in the third main journal of the crankshaft, as shown in Figure 1. Circumferential scratches can be obviously noticed in the curved journal surface. The crank morphology on the curved journal is shown in Figure 1- (b).

The main body of the crack is divided into three sections along the circumferential direction, but there are also branching cracks in the axial direction, and each axial branching crack is located at the section of the circumferential crack. On the other major diameters of the crankshaft, we have not found any abnormalities like cracks.

A. Y. Jiao: School of applied technology, University of Science and Technology Liaoning, Anshan, China. e-mail: jay@ustl.edu.cn.
F. L. Chen, B. H. Liu: School of mechanical Engineering and automation, University of Science and Technology Liaoning, Anshan, China
J. W. Deng: Tianrun Crankshaft Co., Ltd., Wen deng, China

Chemical composition

Took samples was from the third spindle neck to test the chemical composition. Test results are shown in Table 1; the chemical composition and content correspond to the technical requirements [8, 9].

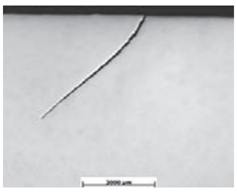
Table 1 **The test result of chemical composition of the material of the crankshaft /wt.%**

Name	Crankshaft	Technical requirements
C	0,422	0,40 – 0,45
S	0,281	0,17 – 0,37
Mn	0,738	0,50 – 0,80
Si	0,0050	≤ 0,025
P	0,0055	≤ 0,025
Cr	1,04	0,90 – 1,20
Mo	0,199	0,15 – 0,25
As	0,0072	≤ 0,008

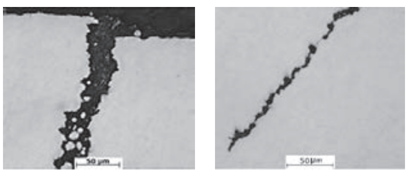
Metallographic observation

The metallographic sample was taken at the location of the shown crack and the cross–section of the metallographic sample was ground and polished. And the cross section was observed with a metallographic microscope. As shown in Figure 1- (b), the shape of the polished state of the circumferential crack is shown in Figure 2. The crack is narrow inside and wide outside. It was possible to judge that crack extends from the surface to the inside by the morphological features. The fact that ends of the crack is sharp and no oxide and other components are found inside can be learnt with further observation. The morphology of the inclusions near the crack is shown in Figure 3. According to the ASTME45–2011A standard rating, inclusions level is D 0.5 which meets the technical requirements of Class D inclusions: the coarse system is less than grade 1, and the fine system is less than grade 3.

To detect the machining quality of the crankshaft surface and some other aspects, another metallographic sample has been taken out at other positions on the crankshaft neck. After grinding and polishing it, the surface of the crankshaft neck was observed. No abnormalities like cracks were observed on the surface of the



(a) Crack overall morphology 12,5 X



(b) Crack partial morphology 400 X

Figure 2 Circumferential crack's morphology

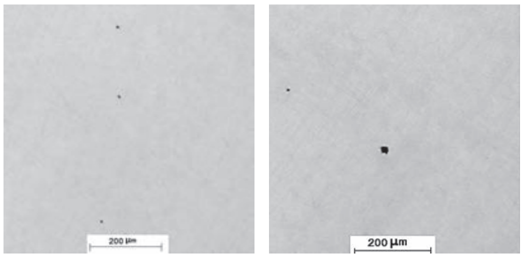


Figure 3 Inclusions near the crack 100 X

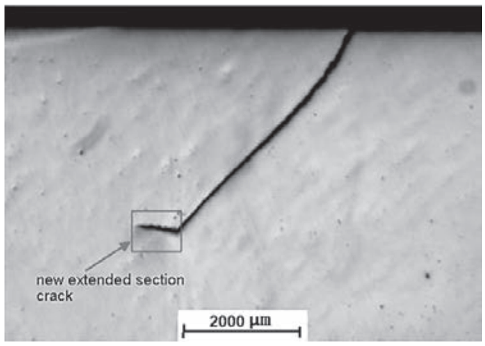


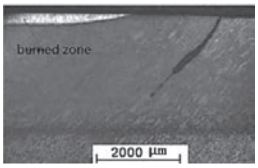
Figure 4 Extended crack morphology 12,5 X

crankshaft. The samples were placed at room temperature for two days, the crack continued to expand, crack morphology after the expansion was shown in Figure 4.

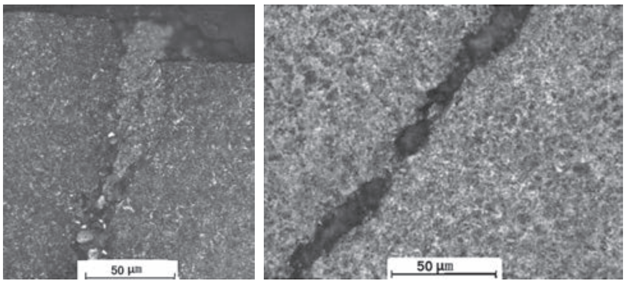
The metallographic samples were observed after being eroded with 4 % nitric acid alcohol and the erosion state morphology is shown in Figure 5. It can be seen from Figure 5 – (a) that it is a hardened layer on the surface of the crankshaft with a depth of 4,83 mm, which meets the technical requirements of the depth of the surface that hardened layer is no less than 2,29 mm, and has a depth of 3,36 mm. The crack was within the surface hardened layer and has a depth of 3,36 mm. A burn band was found on the surface of the crankshaft near the crack, the depth of the burn band was 0,47 mm, and the distance from the crack was 3,52 mm. Micro-hard Vickers hardness test of hardened layer, hardness value was 500HV0.3. According to GB/T 1172 - 1999, the hardness is converted to Rockwell hardness of 49,0 HRC which meets the technical requirements of 45 – 50 HRC surface hardness after quenching and tempering. It can also be found from the direction of the circumferential crack that the direction of the crack is consistent with the direction of the segregation band of the crankshaft journal.

Axial crack fracture

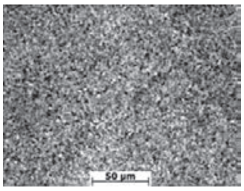
The electron microscope sample was opened along an axial crack. The macroscopic fracture surface morphology of the axial crack was shown in Figure 6. It can be seen that the crack starts from the shaft diameter surface and expands to the depth. The microstructure of the fracture surface was shown in Figure 7. It was seen that the surface of the fracture surface was attached with a layer of material which exhibits a molten state of solidi-



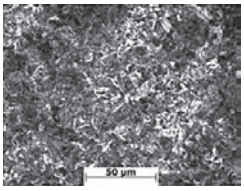
(a) Circumferential crack morphology 12,5 X



(b) Partial appearance 500 X



(c) Hardening layer matrix 500 X



(d) Burned zone 500 X

Figure 5 The shape of the crank's journal

fication. It can be discovered by further observing on the surface morphology of the exposed original fracture that the original crack fracture is a brittle fracture along the crystal. The attachment of the fracture surface was analyzed by energy spectrum. The result is shown in Figure 8. Conspicuously, the attachment is mainly Pb metal elements.

COMPREHENSIVE ANALYSIS

The metallographic analysis shows that the outer edge of the circumferential crack morphology is wide, and its inside is relatively narrow. Therefore, it can be judged that the crack extends from the outside to the inside. Further observation reveals that the tip of the crack was relatively thin and no oxide has been found inside the crack. The inclusion grade near the crack is

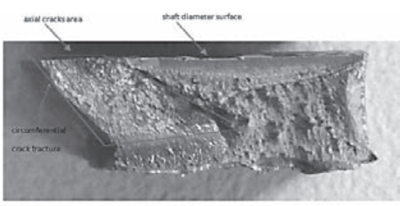
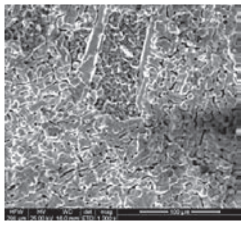
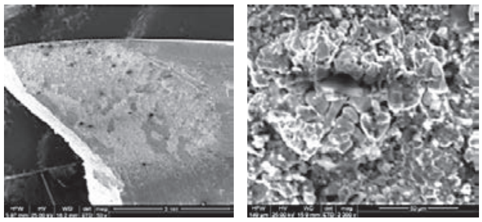


Figure 6 Macroscopic morphology of fracture



(a)



(b) (c)

Figure 7 Axial crack fracture microscopic morphology (Note: a-c is marked directly in the Figure)

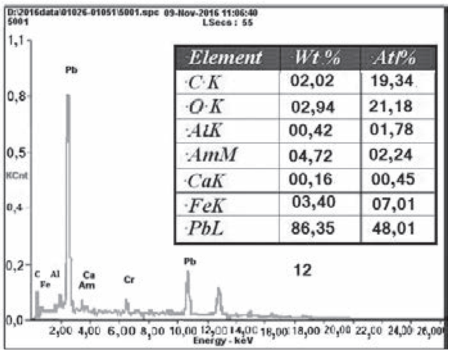


Figure 8 Analysis of the energy spectrum of the surface of the axially crack fracture

not high and corresponds to the technical requirements. There is a hardened layer on the surface of crankshaft with the depth of 4,83 mm, which meets the technical requirements. The circumferential crack is completely in the surface hardened layer with a depth of 3,36 mm. A burn band is found on the surface of the crankshaft journal near the crack. The burn zone has a depth of 0,47 mm and a distance from the circumferential crack of 3,52 mm. The hardness of the hardened layer is 500H V0.3, 49,0 HRC in Rockwell hardness, which meets the technical requirements. It could be seen from the direction of the crack that direction of the crack is consistent with the direction of the segregation band of the crankshaft neck.

The metallographic examination results show that the segregation of band structure from the surface of the crankshaft to the inside is obvious. The crack propagates in a certain direction. The direction along which the crack follows is consistent with the direction of the strip segregation. The material will produce abnormal tissue stress after heat treatment, which is caused by uneven banded structure segregation. From the behavior that the crack self-expands, there is indeed a large residual stress inside the hardened layer of the crankshaft. From the macroscopic appearance, there is a serious circumferential scratch on the surface of the crankshaft neck. Metallographic examination revealed a deep burning band on the surface of the crankshaft. The crack fracture surface contains a molten material having a high content of Pb. This shows that the friction of the crankshaft with the bearing bush during use causes a high temperature phenomenon. The high temperature generated by the friction betweens the crankshaft and the bearing bush causes a large thermal stress in the surface area of the crankshaft neck. There is also a working stress on the surface of the crankshaft during operation. Thermal stress, residual stress and working stress interact with each other. When the tensile superimposed stress exceeds the bearing limit of the crankshaft material, it will first crack along the weak point of the crankshaft (ie, at the segregation band), causing the crankshaft to fail.

Scanning electron microscopy analysis of axial crack fracture: The crack is cracked from the surface of the crankshaft neck and expanded to the depth. A layer of material is attached to the surface of the crack, which material exhibits a molten solid state. Further observations reveal that bare original fracture exhibited brittle fracture characteristics along the crystal. The energy spectrum analysis of the attachment on the fracture surface was carried out, and the contents were mainly Pb metal elements.

CONCLUSION

(1) The chemical composition of crankshaft journal meets technical requirements;

(2) The crack mode of the crankshaft journal is cracking along the crystal brittleness;

(3) There is a serious microscopic segregation in the journal material, which leads to abnormal tissue stress in the crankshaft journal after the heat treatment. This tissue stress plays a major role in the failure process of the crankshaft neck. When the crankshaft journal works, the heat stress is generated by the heat build-up of the friction, as well as the crankshaft itself stress. Crystal brittle fracture occurs in the crankshaft neck, which is caused by the action of three kinds of stresses.

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Note: The responsible translator for English is Siyu Zhu, University of Science and Technology Liaoning, Anshan, China