Engineering Failure Analysis 92 (2018) 84–94

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Failure analysis of a truck diesel engine crankshaft

Xiao-lei Xu*, Zhi-wei Yu

Department of Material Science and Engineering, Dalian Maritime University, Dalian 116026, PR China

ARTICLE INFO

Keywords:
Crankshaft
Multiple source fatigue
Zigzag cracking morphology
Low surface hardness
Stress concentration

ABSTRACT

A truck engine crankshaft fractured during the service. The fracture occurred on the crankshaft big-end on which the timing-gear and the flywheel flange were coupled and the fracture location was just situated at the assembling gap between them. The short cracks inclined at about 45° to the shaft axis initiated from the surface of the crankshaft journal at the timing-gear side and mainly extended to the timing-gear side, leading to a zigzag cracking morphology on the journal surface. A complicated ratchet or star-shaped pattern of fracture typical of multiple fatigue cracks occurred on the fracture surface. The journal surface was locally induction-hardened. The surface hardness and the effective case depth on the hardened journal at the flywheel flange side corresponded to the specification. At the timing-gear side the surface hardness on the hardened journal was much lower than the specified lower limit and a low hardness region of 0.4 mm occurred on the most-surface of the hardened journal within which the hardness values were lower than the specified lower limit. The low surface hardness on the induction-hardened journal made fatigue resistance of the crankshaft decrease to lead to initiation and propagation of fatigue cracks in the weaker region. The assembling gap at which the fracture occurred was structure stress concentration site of the assembly constituted of the crankshaft, the timing-gear and the flywheel flange, equivalent to the deep notch. The excessive tightening of the timing-gear on the journal surface also contributed for the increasing of stress concentration. The fatigue crack origins were easy to initiate due to large stress concentration.

1. Introduction

Diesel engine crankshaft run with a steady torsion combined with a rotatory bending stress [1,2] and the fatigue is the dominant failure mode [3,4]. Poor design, deficient assembly, shaft misalignment, wrong geometry and improper heat treatment process mostly contribute for the fatigue failure of crankshaft [5–7]. The losses due to crankshaft damage include not only crankshaft itself, but also other engine parts affected by the crankshaft failure. Therefore, the failure analysis plays an important role in avoiding recurrence of similar failure and improvement of design, manufacturing techniques, and so on.

It was reported that a truck stalled abruptly while in normal motion and the engine still did not started when trying several times. After disassembling the oil-pan, the phenomena of lacking oil, drawing cylinder and locking bearing-bush were not found. When lifting engine, it was found that the crankshaft big-end fractured. The truck had worked for 28,094 km before failure. The fractured crankshaft was made of S38MnSiV steel. The journal surface is specified to be locally induction-quenched. The effective case depth is specified as 1.2 − 2.8 mm and the case width as 15 mm. The core hardness and the surface hardness on the hardened region are, respectively, specified as HV_{30} 250 − 290 and ≥ HRC 50.

In the present case, the fracture surface of the failed crankshaft showed a very complicated ratchet pattern, very different from the

* Corresponding author.
E-mail addresses: 1944816400@qq.com, xxiaolei@dlmu.edu.cn (X.-l. Xu).

https://doi.org/10.1016/j.engfailanal.2018.05.007
Received 18 January 2018; Received in revised form 1 May 2018; Accepted 18 May 2018
Available online 19 May 2018
1350-6307/

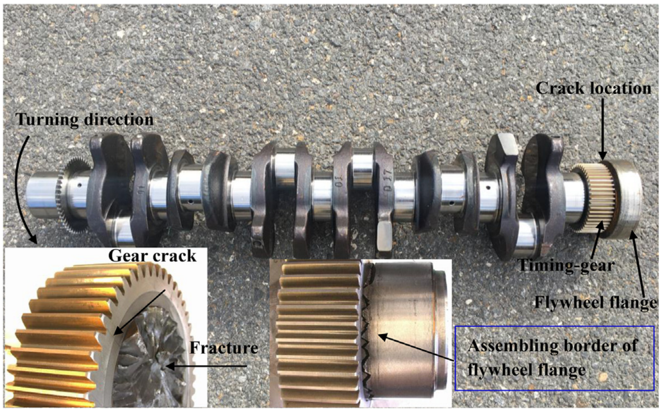

Fig. 1. Failed crankshaft in as received condition.

fractographic morphologies of most failed crankshafts in previous work [1–8]. The present work is focus on analyzing probable failure causes of the crankshaft.

2. Experiment methods

The chemical composition of the failed crankshaft material was analyzed by spectroscopy chemical analysis. The microstructure in various regions was observed by optical microscope (OPM) and scanning electron microscope (SEM). Microhardness profiles from the surface to the interior in various regions were made by Vickers system with a load of 1000 g to determine the effective case depth. The criterion for determining the depth described in the technical specification is the depth of material with hardness greater than $HV_1$425. The crack surfaces were observed visually and using SEM.

3. Observation results

The as-received crankshaft assembly is shown in Fig. 1. At the crankshaft big-end, the timing-gear and the flywheel flange were coupled to the crankshaft journal. Visual inspection revealed that the fracture location was just located at the assembling gap on the journal between the timing-gear and the flywheel flange (marked in Fig. 1). The fracture was basically perpendicular to the shaft axis (seen in left inset of Fig. 1) and zigzag crack morphology was presented on the journal surface (seen in right inset of Fig. 1). It was noted that a radial crack appeared on the surface of timing-gear.

3.1. Observation on fracture surface

The matched fractures are shown in Fig. 2. The fracture surfaces showed dark brown tint due to the presence of thick coverings on the them. Visual examination revealed that the fracture surfaces were rough and exhibited a very complicated ratchet or star-shaped pattern and the sides of the ratchet marks are at approximately ± 45° angle to the shaft axis, similar to the typical fracture of torsional failure [8–11]. The ratchet marks were produced when cracks nucleated at different circumferential points and were linked together creating ridges on the fracture surfaces [12]. The presence of ratchet marks also indicated multiple origins and high stress concentration [13]. The fracture surfaces were heavily damaged by scratching, seen white marks on the matched fractures in Fig. 2. The local plastic deformation direction at the scratching locations on both the matched fractures can be determined according to the scratch marks. The plastic deformation directions at the scratching locations on both the matched fractures were all anticlockwise (indicated by red arrows in Fig. 2). The crankshaft had separated into two parts before disassembling engine in site, reported by the engineer in the manufacturer. Therefore, the scratching marks with the identical turning direction on the matched fracture surfaces cannot be produced either during the disassembling or the transportation of the failed crankshaft.

The cracks on the outer edge of fracture were numbered as C1 to C16 in order to analysis conveniently (seen black arrows in Fig. 3a). The outer edge on the bottom half of fracture showed rough zigzag pattern (C5-C16 sections along the anticlockwise direction), but a circular shear lip of 2.5 mm wide appeared on the outer edge on the top half of the fracture (C5-C16 sections along the clockwise direction). According to the observation on the macro-fracture, it can be concluded that the crack origins were located at the outer edge on the bottom half of fracture (C5-C16 sections along the anticlockwise direction) and the final fraction area at the outer edge with the circular shear lip on the top half of the fracture (C5-C16 sections along the clockwise direction).

Additionally, close-up stereomicroscope observation on the gear crack was conducted. It can be seen that the gear crack propagated from internal surface toward the external surface (from A to B), then extending to the tooth flank (from B to C) and stopping at the tooth flank (location C), seen in Fig. 3b. It was noted that the gear crack was not passing through the tooth groove. Appearance of a radial crack on the tooth flank of the timing-gear should be more likely a consequence of a bursting of internal hole of gear when the crankshaft cracks extend to the journal surface on which the timing-gear was tightened, rather than resulting from the excessive