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Case study

Analysis of a failed rocker arm shaft of a passenger car engine

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ABSTRACT

This paper investigates the failure of a rocker arm shaft of a passenger car. The shaft failed by brittle fracture across one of the four holes supporting the shaft into the cylinder head. The running distance of the engine just before failure was 40,626 km. Visual examinations of etched sections of the failed shaft and a *new one* revealed four distinct zones of darker etching appearance. These zones correspond to the four locations where the rocker arms fit the shaft.

Microscopic observations of the failed shaft revealed that the four dark-etching areas are surface hardened zones of martensitic microstructure. Furthermore, scanning the microstructure along the failed shaft showed that the heat treatment was *so mistakenly extended by excessive heating* so that the structure of the shaft near the supporting holes contains considerable content of martensite phase. This conclusion has been confirmed by the results of hardness measurements along the surface of the shaft.

Microscopic investigations of the failed shaft revealed the presence of microcracks close to the supporting holes. These cracks may have been induced in the shaft by the non-uniform cooling during quenching in the course of heat treatment, or may be nucleated by repeated loading during service. This premature failure has occurred by the rapid crack propagation because of the lower fracture toughness of the martensite.

1. Introduction

Suddenly during the start-up of a passenger car engine, a high abnormal noise accompanied by a jerky vibration of the engine had been manifested. After dismantling, the local dealer service found that the rocker arm is broken near the middle as shown in Fig. 1(a). The fracture passes across the hole of one of the supporting bolts as shown in Fig. 1(b). Visual examination of the car engine showed that the running distance of the engine just before failure was 40,626 km during which regular services had been given to the engine as recommended by the manufacturer's manual.

One of the major causes of component failure is faulty manufacturing. This includes all effects that increase brittleness or those inducing cracks and or stress raisers in the component. Improper heat treatment has been considered as major causes of many failures in the literature. Examining the causes of the problem, we came across the following cases.

Torronen et al. [1] examined the brittle fracture behaviour of a Cr-Mo-V alloyed pressure vessel steel after a variety of quenching and tempering treatments. They found the effective grain size of martensitic microstructure in the alloyed steel.

Lee et al. [2] examined the failure of a rocker arm shaft for passenger car in the design stage and the robustness of its boundary condition using orthogonal arrays and ANOVA. They found that a fatigue crack in rocker arm shaft was initiated at

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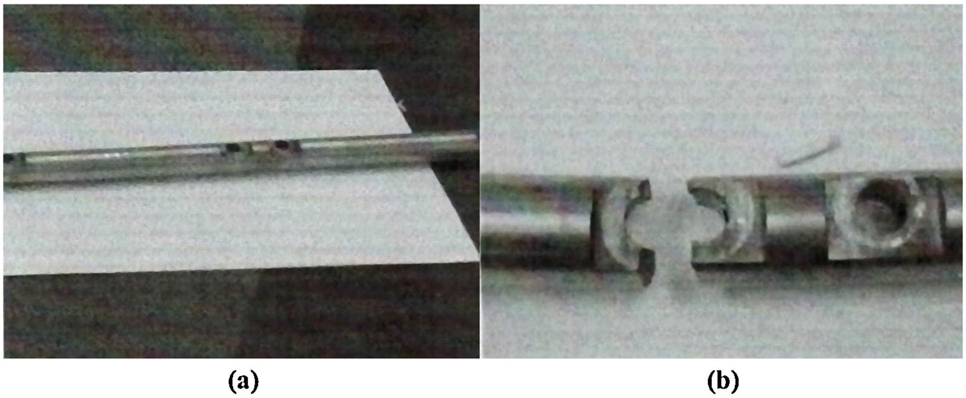

Fig. 1. Photograph of the failed rocker arm shaft.

through hole and subsequently propagated along its sidewall. An extension of this work [3] shows that the failure stress conditions of this kind of parts should be analysed before installation. They suggested FEA and SEM analysis to estimate the stress conditions.

Muhammad et al. [4] investigated the failure of a diesel engine rocker arm and observed metal particles and scratches on the crack area. Hence, they attributed the failure to a fatigue failure due to stress localisation.

Monlevade et al. [5] suggested that the untempered martensite leads to the appearance of microcracks that develop into premature catastrophic failures due to its very high hardness. The failure may be avoided by considering the final heat treatment process, the pre-heating prior to processing, and the proper assembly of the parts to avoid vibration or relative movement that may cause friction between parts during use.

In their detailed paper, Ibrahim and Sayuti [6] studied the hardness, microstructure and cracking mechanism of hardened and tempered AISI 1045 (CF 45 in DIN 17212-72 standrad). They concluded the proper heating and cooling conditions to avoid cracking due to martensite formation. Another study [7] shows the effect of forming various grain size of austenite on the martensite morphology, and consequently on the mechanical properties such as hardness and fatigue. It is concluded that the privileges of controlling the temperature and holding time of the heat treatment process lead to some enhancements of martensite morphology.

Mateo et al. [8] studied the fatigue resistance of two different samples from austenitic stainless steel grade AISI 301 LN. The first sample was annealed and the second sample was cold rolled. They observed different fatigue limits due to the transformation of austenite to martensite. They hypothesised that the fatigue differences are attributed to the accumulation of plastic deformation during the treatment which is different from process to another.

From this short review, it is clear that heat treatment, grain size, and the appearance of martensitic phase are main failure causes of engine components.

2. Experimental work

This paper presents the procedure used to investigate the failure of the rocker arm shaft. The shaft material was investigated by chemical analysis. Microscopic investigations were applied to compare the microstructure of the failed shaft with the microstructure of a new shaft. The shaft hardness was measured to investigate the failure cause.

2.1. Characterisation of the shaft material

Chemical analysis of the shaft material gave the composition listed in Table 1. According to DIN 17212-72 standrad, CF 45 is the nearest grade to this steel. This steel belongs to steel grades suitable for surface heat treatments. The recommended heat treatment condition of the DIN grade is given in Table 2. These conditions are general and may change according to the application.

2.2. Microscopic investigations

The etched sections of the new shaft and failed shaft were examined. The macro-etching of the new shaft showed areas of darker etching colours where rocker arms get into contact with the shaft as shown in Fig. 2(a). It is observed that the darker etching zones are equally spaced, regular and correspond to the areas of rocker arms contact. Conversely, the darker etching zones of the failed shaft are wider and irregular and extend to the hole locations as shown in Fig. 2(b) and (c).

Observation of the microstructure of the failed shaft at the interface between the two different etching zones close to the hole, arrow location in Fig. 2(c), showed different microstructures at both sides of the interface as shown in Fig. 3. The dark