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Case study

Failure analysis of axle shaft of a fork lift

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ABSTRACT

An axle shaft of fork lift failed at operation within 296 h of service. The shaft transmits torque from discrepancy to wheel through planetary gear arrangement. A section of fractured axle shaft made of induction-hardened steel was analyzed to determine the root cause of the failure. Optical microscopies as well as field emission gun scanning electron microscopy (FEG-SEM) along with energy dispersive spectroscopy (EDS) were carried out to characterize the microstructure. Hardness profile throughout the cross-section was evaluated by micro-hardness measurements. Chemical analysis indicated that the shaft was made of 42CrMo4 steel grade as per specification. Microstructural analysis and micro-hardness profile revealed that the shaft was improperly heat treated resulting in a brittle case, where crack was found to initiate from the case in a brittle mode in contrast to ductile mode within the core. This behaviour was related to differences in microstructure, which was observed to be martensitic within the case with a micro-hardness equivalent to 735 HV, and a mixture of non-homogeneous structure of pearlite and ferrite within the core with a hardness of 210 HV. The analysis suggests that the fracture initiated from the martensitic case as brittle mode due to improper heat treatment process (high hardness). Moreover the inclusions along the hot working direction i.e. in the longitudinal axis made the component more susceptible to failure.

1. Introduction

Axles are connected within vehicles to perform two important functions: (i) they transmit torque from variance to wheel through planetary gear arrangement, and (ii) they maintain the position of the wheels comparative to each other and to the body of the vehicle. In most non-commercial vehicles, the circular motion of the drive wheels is maintained by means of axle shafts, which are integral component of the rear axle [1]. The shafts are installed in the tire's wheel well near the differentials and stretch across the bottom of the vehicle. Often during operation, the axle shafts are subjected to heavy torque due to loads or sudden acceleration and therefore, they are manufactured from different grades of hardened steels. There were four numbers of such axle shafts in service at the fork lift, out of which two failed. The fork lift is used to lift wire rod coils from the coil yard. An axle shaft of fork lift failed at operation within 296 h of service. No damage was reported in the other components of the assembly. Sudden jerk was observed before failure, which might be due to the effect of overloading. The fractured shaft with a diameter of about 7 cm was manufactured by the forging of 42CrMo4 grade of steel given an induction

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hardening treatment to produce a case of 3–4 mm in depth as per specification. A section of fractured rear axle shaft was removed from the location to determine the most feasible cause of failure.

2. Experimental procedure

The failed axle shafts were collected from the plant for investigations. The samples were cleaned with acetone to remove dirt for visual examination prior to metallographic sample preparation. Transverse and longitudinal specimens were made from the fractured end of the failed samples for conducting optical microscopic examination. These samples were individually mounted in conductive mounting and polished by conventional metallographic techniques for scratch free surface. The polished samples were etched in 3% Nital solution (3 mL HNO_3 in 97 mL ethyl alcohol), and both un-etched and etched samples were examined under an optical microscope. The micro-hardness of different location which was observed in the failed samples was determined in a pneumatically controlled automatic micro hardness tester (Leco-LM247$_{AT}$). An applied load of 100 gf was used during testing, and several indentations were made to determine the hardness of the failed component. Field Emission Gun Scanning Electron Microscopy (FEG-SEM) of the samples was also carried out to identity exact phases present in the samples. The analyses were performed at 15 keV accelerating voltage and 5^{10-8} A probe current.

3. Results and discussions

3.1. Visual observation

Fig. 1a is a schematic illustration of the rear axle shaft showing the approximate location of the fracture near the wheel mounting flange. A photograph of the section received for analysis is shown in Fig. 1b. The axle shaft failed in shear mode at almost 45° to the longitudinal direction under torque [2,3]. It is observed that the fracture surface consists of two distinct regions: (i) a relatively smooth annular region at periphery marked as A where the fracture was initiated, and (ii) a rough core marked as B (shown in Fig. 1c).

3.2. Chemical analysis

The chemistry of the failed axle shaft matches with 42CrMo4 grade of steel. Chemical analyses of the failed sample are given in Table 1.

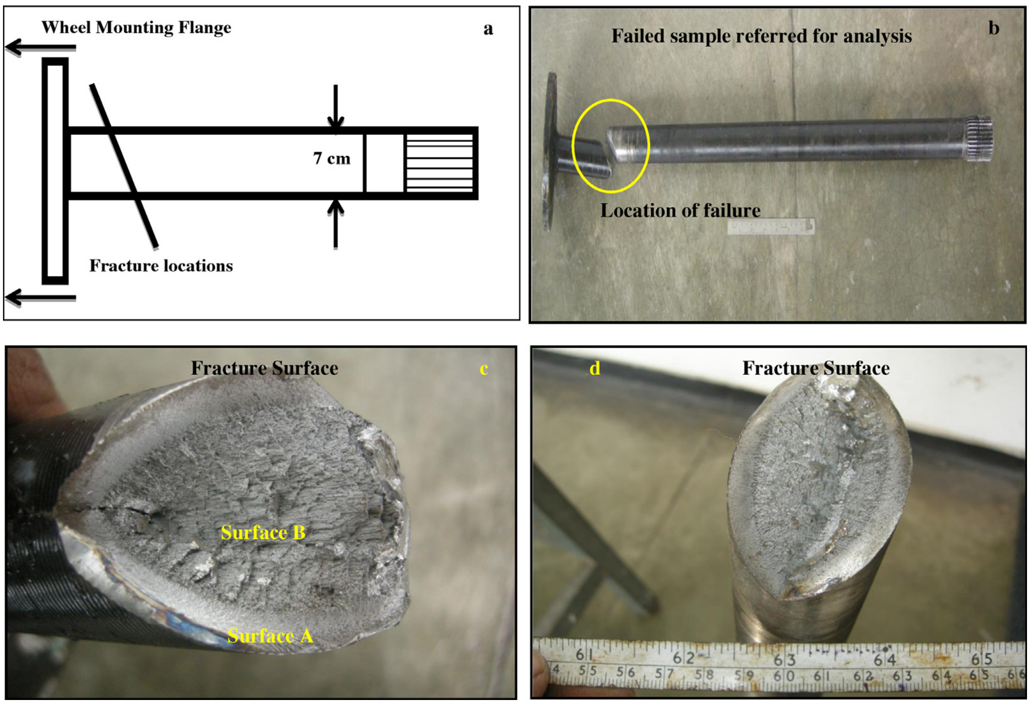

Fig. 1. (a) Schematic illustration of the rear axle shaft showing the approximate location of the fracture near the wheel mounting flange; (b) general view of the failed axle shaft referred for analysis; (c) closer view of the fracture surface of the failed component.