Case Studies in Engineering Failure Analysis 2 (2014) 9–14

Contents lists available at ScienceDirect

Case Studies in Engineering Failure Analysis

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

Case study

Analysis of abnormal fatigue failure of forklift forks

George Pantazopoulos *, Athanasios Vazdirvanidis, Andreas Rikos, Anagnostis Toulfatzis

ELKEME Hellenic Research Centre for Metals S.A., 252 Pireaus Str., 17778 Athens, Greece

ARTICLE INFO

Article history:
Received 30 September 2013
Received in revised form 15 October 2013
Accepted 5 December 2013
Available online 28 December 2013

Keywords:
Fatigue
Fractography
Forklift forks
Failure analysis

ABSTRACT

The analysis of an abnormal failure of forklift forks is presented in this work. The investigation results suggested that failure occurred due to fatigue mechanism followed by sudden overload fracture. The orientation of fatigue fracture indicates abnormal lifting operation, favouring crack initiation from outer fork area which is the compression designed zone. Moreover, various surface flaws and weakness areas (such as surface marks, decarburized microstructures and weld zones) identified on the outer fork zone, compromise fatigue strength inducing premature crack nucleation and fast growth towards final failure.

1. Introduction and background information

Cyclic loading takes place under normal operation condition of various machine components, resulting in the action of fatigue failure mechanism [1,2]. Apart direct production equipment, auxiliary machinery, such as transportation and weight lifting members are subjected to harsh stress and environmental conditions. Forklift trucks are common production vehicles which convey raw materials to the production line, scrap and final products to the storage areas or to the transportation trucks. The load support members of forklift forks are subjected to repetitive stress conditions of a variety of load and frequency spectra, including loading and unloading cycles and vibrations coming from moving on irregular terrain conditions. Failure analysis of fork lift forks were also studied in Refs. [3,4]. The presence of weld repair of forklift fork suggest a prominent condition for fatigue cracking (see also [3]), while the abusive and overloading conditions (high loads and running speeds) induce fatigue failure, see also [4]. An incident of forklift forks failure, occurred in a metalworking plant environment, activated a failure analysis procedure for root cause investigation. The forklift forks (cross section dimensions, $b \times h = 150 \times 50$ mm) failed after almost seven years in service. The maximum loading conditions involve 1200 kg total weight lifting with a maximum distance of the centre of gravity from the vertical beam of 3 m. This leads to a maximum bending moment (M_b) of 18,000 N m per single fork. Visual, macro-inspection, optical and scanning electron microscopy for fractographic and microstructural evaluation along with hardness testing were used as the principal analytical techniques in the context of the present investigation.

* Corresponding author. Tel.: +30 2104898263; fax: +30 2104898268.
E-mail address: gpantaz@halcor.vionet.gr (G. Pantazopoulos).

2213-2902
http://dx.doi.org/10.1016/j.csefa.2013.12.005

Table 1
Chemical composition of the broken forklift fork (Sample 1) as compared to the related steel grade (% wt.).

Sample/Std	C	Mn	S	P	Si	Cr	Ni	Mo	Cu	Al	Ti
Sample 1	0.34	0.65	0.01	0.01	0.28	0.92	0.07	0.03	0.12	0.08	0.02
34Cr4 (W.Nr. 1.7033)	0.30–0.37	0.60–0.90	≤0.035	≤0.035	≤0.40	0.90–1.20	–	–	–	–	–

2. Experimental procedure

Low-magnification inspection of surface and fracture morphology was performed using a Nikon SMZ 1500 stereomicroscope. Microstructural characterization was conducted in mounted cross-sections. Wet grinding was performed using successive abrasive SiC papers up to #1200 grit, followed by fine polishing using diamond and silica suspensions. To reveal the microstructure, immersion etching was performed using standard Nital 2% solution (2% nitric acid in ethanol) followed by ethanol rinsing and hot air-stream drying. Metallographic studies were performed using a Nikon Epiphot 300 inverted metallurgical microscope. Hardness testing was performed using an Instron-Wolpert hardness tester using Rockwell C Hardness technique and an Instron-Wolpert Vickers micro-indentation device under 0.2 kg applied load. In addition, high magnification fractographic observations were conducted to ultrasonically cleaned specimens, employing a FEI XL40 SFEG Scanning Electron Microscope using secondary electron (SE) detector for topographic evaluation. SE imaging was also realized in gold sputtered etched sections for metallographic characterization.

3. Investigation findings

3.1. Chemical analysis

The chemical composition of the fractured fork, analyzed by Optical Emission Spectroscopy (OES), indicated that the forks are made of a common structural steel grade 34Cr4 (W.Nr. 1.7033), see Table 1 [5]. This steel grade is a heat treatable alloy commonly used as a machine element in axle and shaft fabrication.

3.2. Fractographic analysis

Fractographic evaluation constitutes a powerful analytical technique dedicated to identify the fracture mechanism(s) in the context of failure analysis of machine components, see also Ref. [6]. The overall view of the fracture surfaces of both forks is presented in Fig. 1. The macroscopic fracture patterns acquired during visual examination suggest the occurrence of bending fatigue loading mechanism (Figs. 1 and 2). The orientation of fatigue zone advocates that crack initiation occurred at the outer fork side, which constitutes the designed compression zone. Detailed assessment of fracture surfaces identified some characteristic features of fatigue failure: (i) beach marks which constitute fatigue crack front progression marks and (ii) ratchet marks which are signs of multiple crack initiation due to high stress concentration (Fig. 2). Fractographic features of fatigue fractures are also presented in Refs. [7–9]. The exact fatigue mechanism is rather consistent to unidirectional bending while the extent of fatigue zone is likely typical for moderate to high loading conditions. Macro-fractographic observations indicate that Fork A is rather the primarily failed component, resulting in unbalanced stress state concentrated to Fork B, where fatigue zone seems to be developed in a lesser extent (see Figs. 1 and 2).

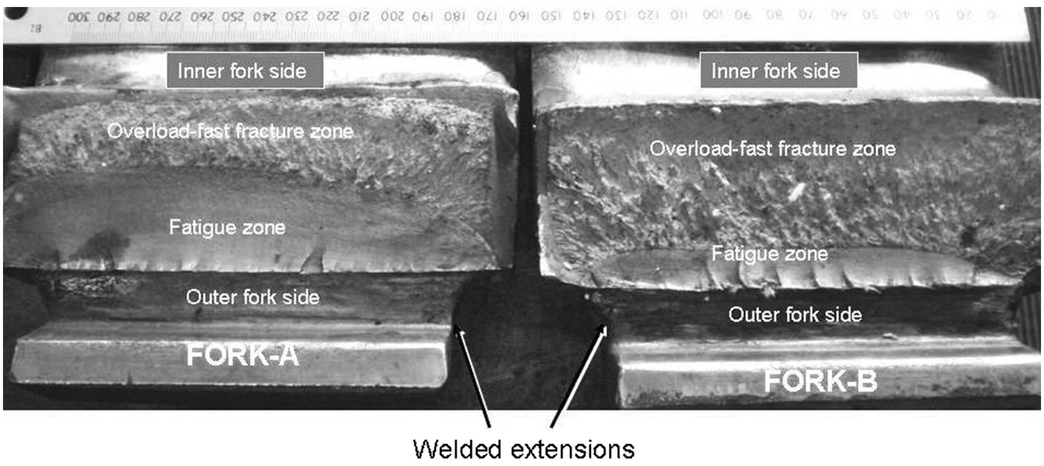

Fig. 1. General view of the fractured forklift forks.