Case Studies in Engineering Failure Analysis 5–6 (2016) 1–9

Contents lists available at ScienceDirect

Case Studies in Engineering Failure Analysis

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

Effect analysis of an arc-strike-induced defect on the failure of a post-tensioned threadbar

Jesús Chao *, Carmen Peña

Mechanical Testing Laboratory, Centro Nacional de Investigaciones Metalúrgicas (CENIM-CSIC), Avda. Gregorio del Amo 8, 28040 Madrid, Spain

ARTICLE INFO

Article history:
Received 3 September 2015
Received in revised form 30 October 2015
Accepted 2 November 2015
Available online 10 November 2015

Keywords:
Prestressing threadbar
Arc strike
Perlitic steel
Surface cracks
Fracture toughness

ABSTRACT

A temporary threadbar used for precast segmental construction broke during the post-tensioning stage before reaching the service load. Failure analysis showed that the premature failure of the bar was due to the presence of an arc strike. The arc strike effects on the material and threadbar integrity are considered.

1. Introduction

Previous works have demonstrated that the mechanical properties of pre-stressed steel bars are sensitive to the presence of small (<1 mm) surface defects, such as scratches, cracks or pits, because of a limited material fracture toughness and a necessity to apply a high (0.7 times the ultimate tensile load) stress level [1,2].

This study analyzes the reason why a temporary threaded high-strength bar (UTS > 1000 MPa; Ø = 26.5 mm) used for precast segmental construction broke during the post-tensioning process before reaching 0.7 times the ultimate tensile load. Therefore, a complete characterization of the threadbar was performed, which included fractured bar failure analysis and fracture surface fractographic analysis. Based on the obtained information, a discussion of the results was undertaken.

2. Threadbar characterization

2.1. Chemical composition

The chemical composition of the threadbar, determined using glow discharge optical emission spectrometry (GDOES), is shown in Table 1. This chemical analysis verifies the compositional limits ($S < 0.05$, $P < 0.04$) specified in the ASTM A722 standard. Furthermore, this composition is in accordance with the chemical composition of UNS G10700 steel.

* Corresponding author.
E-mail address: jchao@cenim.csic.es (J. Chao).

http://dx.doi.org/10.1016/j.csefa.2015.11.001

Table 1
Chemical composition of the prestressing bar.

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Cu
Weight %	0.67	0.28	0.85	0.011	0.014	0.026	0.011	<0.010	0.028

2.2. Microstructural analysis

Microstructural analysis was performed on a cross section far from the fracture, which was etched with 2% Nital. The microstructure was a fine perlite in the bar center and a tempered martensite on the surface ring that was approximately 1.4 mm deep, Fig. 1. These microstructure differences are caused by cooling rate differences from the rolling temperature to room temperature during bar processing.

2.3. Hardness tests

Because of the abovementioned microstructural differences, Vickers hardness (9.8 N) tests were performed along the cross section radius of the bar. No significant differences in hardness were found. The hardness value was 343 ± 19 ($n = 22$), the maximum value (≈370 HV1) was located near the surface, and the minimum value of 286 HV1 was near the cross section center. No clear trend of the hardness with distance from the surface was observed.

2.4. Tensile tests

Two types of samples were tested: threadbar samples with a 700 mm length and tensile specimens with a 24.4 mm diameter and 150 mm gage length. This diameter was chosen to obtain from the threadbar cross section, the maximum circular cross section at the specimen gage length. Tensile tests of the threadbars were carried out according to ISO 15630-3 [3], whereas those of the specimen were carried out according to ISO 6892-1 [4]. Table 2 presents the pull test results. To obtain the YS and UTS of the threadbar, the nominal cross section (552 mm^2) was considered. The obtained results for both test types agree with each other and confirm the ASTM A722 standard specifications [5]. In both cases, the fracture occurred after an appreciable plastic deformation. Apparently, the fracture initiation modes are different, as shown in Fig. 2. In the tensile specimen, the fracture initiates at the cross section center, and in the threadbar, the fracture initiates at the surface. This can be explained by taking into account the fact that the ductile fracture initiates at the location where the stress triaxiality state is maximum. For the tensile specimen, the fracture initiates at the center of the cross section, which is the location where the stress triaxiality state is maximum (once the necking has developed) after, the fracture concentrically advanced via microvoid coalescence and finalized unsteadily via a cleavage mechanism with isolated ductile areas. For the threadbar, the fracture occurred similarly, except for the fracture initiation, which occurred at the surface ridge basis because this is the location where the stress triaxiality state is maximum. It is likely that small elongation differences were caused by these fracture initiation mode differences.

2.5. Fracture toughness tests

The single edge notch bend specimens with a 10 mm thickness, 10 mm width and 55 mm length were machined from the bar according to the ASTM E1820 standard [6]. The provisional fracture toughness K_Q values were found to be invalid for obtaining a K_{Ic} value according to the specifications in the abovementioned ASTM standard. Thus, the provisional J_Q values were calculated from the load versus load-line displacement curves according to the ASTM E1820 standard [6]. Because the J_Q values meet the size criteria of the standard, they qualify as J_c values. This implies that the obtained values are insensitive to the specimen dimensions. The fracture toughness K_{Jc} value was calculated from the J integral value at the onset of a brittle fracture J_c using the following expression:

$$K_{Jc} = \sqrt{\frac{J_c E}{1-\upsilon^2}} \quad (1)$$

where E is Young's modulus and υ is Poisson's ratio.

Thus, the valid values of the K_{Jc} fracture toughness were: 71.2–69.5–70.5 MPa m$^{1/2}$.

Fig. 3 shows a typical SEM image of the fracture mode of the specimens. It demonstrates the fatigue precrack, the stretching of the fatigue precrack-tip with some isolated microvoids and the final fracture via cleavage.

3. Failure analysis of the threadbar

The threadbar failure occurred without plastic deformation. When the fracture surface was observed with a naked eye, some directional tear ridges were observed (Fig. 4(a) and (b)). By tracing back the directional features it was possible to identify the fracture initiation zone. The fracture started from a linear segment with an approximate 9 mm length located