C. R. Mecanique 344 (2016) 596–602

Contents lists available at ScienceDirect

Comptes Rendus Mecanique

www.sciencedirect.com

Effect of the defect initial shape on the fatigue lifetime of a continuous casting machine roll

Oleh P. Yasniy [a,*], Yuri Lapusta [b]

[a] Department of Mathematical Methods in Engineering, Ternopil Ivan Pul'uj National Technical University, Ruska 56, Ternopil, 46001, Ukraine
[b] French Institute of Advanced Mechanics, Institut Pascal/IFMA/CNRS/UBP/Clermont Université, Campus de Clermont-Ferrand, BP 265, 63175 Aubière cedex, France

ARTICLE INFO

Article history:
Received 14 September 2013
Accepted 2 April 2016
Available online 4 May 2016

Keywords:
Fatigue
25Cr1MoV steel
Continuous casting machine roll
Stress intensity factor
Semi-elliptical surface crack
Lifetime

ABSTRACT

The article deals with the influence of the defect initial shape on the residual lifetime of a continuous casting machine roll made of 25Cr1MoV steel. Based on this approach, previously proposed by some authors, the growth of the surface fatigue crack was modeled in a roll under loading and temperature conditions that are close to operational ones, taking into account the statistical distribution of the C parameter of Paris' equation. Dependencies of the continuous casting machines roll fatigue lifetime on the initial defect shape and critical defect sizes are obtained.

1. Introduction

Lifetime prediction of structures subjected to fatigue and thermal fatigue, corrosion, and other factors is of great importance. These structures include elements of thermal and nuclear power plants [1–4], pipelines [5], rolls of continuous casting machines [6–8], railway axles [9], etc. Note that multiple cracking is a typical mechanism for all these structures and that a variety of approaches was proposed for the study of multiple cracks and defects in structural elements and related problems [10–15]. The multiple cracking is often observed in the rolls of continuous casting machines and equipment for hot rolling that undergo cyclic thermo-mechanical loading. This loading leads to the emergence and growth of multiple surface cracks [6,16,17] which can affect significantly the structure's residual lifetime.

This article studies the influence of the initial shape of such crack on the structure residual lifetime considering the example of a continuous casting machine roll (CCMR). The roll's lifetime is generally determined by surface crack growth under thermal fatigue up to a critical size. Generally, it depends on the properties of the material, on the applied cyclic mechanical stresses and temperature, on the rolling speed, and on other factors. Note that the residual lifetime of structural elements with surface defects can also significantly depend on the initial defect shape [18–21]. The effect of temperature, frequency and loading waveform on the fatigue crack growth rate of CCMR material was studied in the work [22]. The fatigue crack growth rate in 15Cr13Mo steel almost does not depend on temperature (20 °C and 600 °C). The increase of frequency loading from 0.01 to 0.1 Hz augments the fatigue crack growth rate for $\Delta K < 24\ \text{MPa}\sqrt{\text{m}}$ and reduces by more than two times for $\Delta K > 28\ \text{MPa}\sqrt{\text{m}}$ [22].

---

[*] Corresponding author. Tel.: +380 352526613; fax: +380 352254983.
E-mail address: oleh.yasniy@gmail.com (O.P. Yasniy).

http://dx.doi.org/10.1016/j.crme.2016.04.002

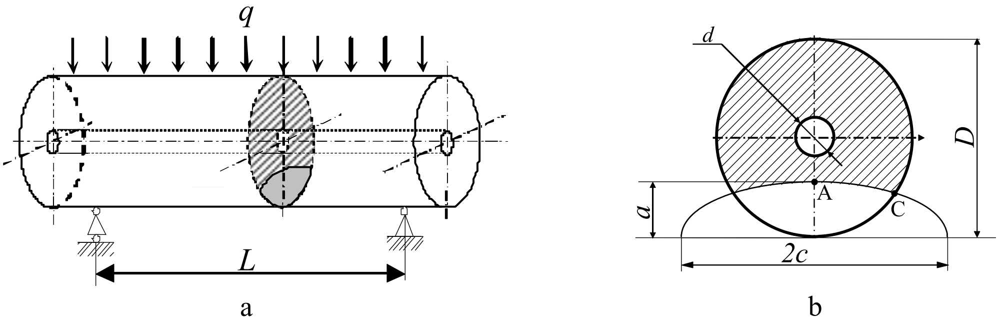

Fig. 1. a) Scheme of the roll and its loading; b) cross-section with a semi-elliptical crack.

The change in the shape of the surface fatigue cracks in cylindrical specimens of railway axles made of 30NiCrMoV12 steel induced by rotating bending has been studied in [18]. It was found that when the relative depth of the surface crack $\alpha = a/D$ is divided by 10 (from 0.025 to 0.25), the shape a/c of the propagating semi-elliptical crack decreases from 0.9 to 0.6, where a is the crack depth, D is the specimen diameter, c is the half crack length. The surface cracks in the railway axles are mostly semi-elliptical [18,21].

In the work [20], it was shown that regardless of the loading scheme (reverse or rotating bending) and initial crack shape (semi-elliptical or semi-circular) for a relative crack depth of more than 0.16, the crack shape can be described by a dependency on the relative depth.

The topology of surface cracks in entirely forged CCMR made of 25Cr1MoV steel, dismounted from service after 4500 melts, was studied in [23]. The cracks in the plane perpendicular to the roll axis are by from 1.5 to 1.8 times deeper than those in the axial one, and have crack shape 2.5 for crack depths up to 6 mm and crack shape 4 for cracks deeper than 6 mm.

Cracking of rolls and other parts of the rolling equipment under thermal fatigue was modeled, for example, in [24,25]. However, the deterministic approaches do not take into account the scatter of mechanical properties. Using them, one cannot assess the probability of reaching the critical crack size and to get the probability distribution, which is function of the structure's residual lifetime. In contrast, statistical and probabilistic fracture mechanics methods allow us to obtain the distribution function of the residual lifetime or the critical crack size [26,27]. Such approaches to fatigue crack growth modeling in structural elements are based on the analysis of the stress state and take into account the scatter of crack growth resistance characteristic of certain conditions [28,29] described by the known distribution laws. To describe the parameters of the Paris equation, the normal and the log-normal distribution are mostly used [30].

The aim of this paper is to estimate the structural elements' residual lifetime depending on the shape of the initial defect, considering the statistical scatter of the characteristics of crack growth resistance. This analysis is carried out using the example of a CCMR. Based on this approach, previously proposed by some authors, the growth of a surface fatigue crack was modeled in a roll under loading and temperature conditions that are close to the operational ones, taking into account the statistical distribution of the parameter C in Paris' equation. Dependencies of the CCMR fatigue lifetime from the shape of the initial defect are obtained.

2. Modeling of surface fatigue crack growth and residual lifetime assessment

Consider a roll that is a thick-walled hollow cylinder with an outer diameter $D = 320$ mm and a cooling hole with diameter $d = 80$ mm (Fig. 1a). The distance between the supports is 2000 mm. The semi-elliptical fatigue crack in the central cross-section of the roll perpendicular to its axis was considered (Fig. 1b). The roll is made of 25Cr1MoV steel. To predict the residual lifetime, we have employed the approach adopted in [8]. The initial conditions were the following: initial crack depth $a_0 = 15$ mm, initial crack shape $a_0/c_0 = 1/16; 1/8; 1/4; 1/2$. To simplify the model, we assume that the temperature fluctuations during one rotation are insignificant. The temperatures in the middle roll cross-section and on the surface of the roll are equal to 375 °C and 600 °C, respectively.

The stresses in the roll are caused by the pressure of the liquid metal and the weight of the slab. The semi-elliptical fatigue crack growth was modeled under stress ratio $R = K_{\min}/K_{\max} = 0$, where $K_{\min}$, $K_{\max}$ are the minimum and maximum stress intensity factors (SIFs), respectively. The stress range $\Delta\sigma = \sigma_{\max} - \sigma_{\min} = 257$ MPa, where $\sigma_{\min}$ and $\sigma_{\max}$ are the minimum and maximum normal stresses of the loading cycle, perpendicular to the crack plane. The stress range was determined at the surface of the roll.

The SIF at the deepest point (Fig. 1b) and at the point on the surface of the semi-elliptical crack in the hollow cylinder was calculated according to the data of Carpinteri [31]. The SIF range for mode I at points A and C was calculated by the formula

$$\Delta K_{\mathrm{A(C)}} = \Delta\sigma\sqrt{\pi a}\,Y_{\mathrm{A(C)}}$$