Engineering Failure Analysis 93 (2018) 224–240

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Multiple cracks failure rule for TBM cutterhead based on three-dimensional crack propagation calculation

Wei Sun, Ye Zhu, Jun-Zhou Huo*, Xiao-Hong Chen

Dalian University of Technology, Dalian, China

ARTICLE INFO

Keywords:
TBM cutterhead
Crack propagation
Three-dimensional crack
Multiple cracks
Stress intensity factor
Crack propagation path

ABSTRACT

Practically, there is multiple cracks interpenetrating in TBM cutterhead, which gives rise to its failure prematurely. While the existing theoretical formulas and calculating methods cannot calculate its fatigue failure process under dynamic loading. In view of such situation, crack cutting sampling of TBM cutterhead after service and its fracture failure analysis were performed to clear that its fracture failure is mainly brittle fracture, based on which, A three-dimensional finite element crack propagation model was established to calculate the crack propagation process under dynamic loading. Stress intensity factor of compact test specimens is calculated by standard formula, and the growth paths of crack are got from multiple cracks fatigue tests, compared the two results obtained above to verify respectively the accuracy of the proposed method in calculating stress intensity factor and its growth path. It is confirmed that the two results about the change of stress intensity factor is basically match, and the maximum error of the growth path of the multiples crack model and the test result is about 3.7% within the permissible range. It is proved that the proposed method is feasible to calculate the multiple cracks failure process under the dynamic loading. Finally, the growth processes of collinear multiple cracks, parallel multiple cracks, nonparallel multiple cracks, and penetrating multiple cracks were calculated. The results show that the stress intensity factor at the intersection of collinear cracks decreased by about 26%, compared with a single crack. Parallel and non-parallel multiple cracks are attracted to each other as the cracks propagate in the process of growth and the stress intensity factor gradually decreases. Although the growth path and stress intensity factor do not change, the crack stops expanding, with the crack tip penetrates through another crack. The failure criterion of TBM cutterhead and the rule of interpenetration of multiple cracks proposed in this paper are the theoretical basis and technical support for the its life prediction and risk prediction.

1. Introduction

Full face rock tunnel boring machine (TBM) as a key component of the full-face rock tunnel boring machine (TBM), the cutterhead has the roles of crushing rock and stabilizing the tunnel face, which affects the boring performance and efficiency of the whole machine [1].Due to the complicated geological environment and the variability of construction parameters, the risk of cutterhead accidents accounted for more than half of the total risk of TBM accidents, these accidents make TBM excavation efficiency and cutter life greatly reduced [2, 3]. Among them, the fatigue failure is the main reason for the failure of the cutterhead. There are a large

* Corresponding author.
E-mail address: huojunzhou@dlut.edu.cn (J.-Z. Huo).

https://doi.org/10.1016/j.engfailanal.2018.07.002
Received 28 April 2018; Received in revised form 28 May 2018; Accepted 5 July 2018
Available online 11 July 2018
1350-6307/

Fig. 1. Multiple cracks failure of TBM cutterhead.

number of cracks on the cutterhead surface, Moreover, the phenomenon of multiple cracks intersect often occurs, which results in the failure of the cutterhead when it fails to meet the expected requirements. as shown in Fig. 1. Therefore, the research on failure principle of multiple cracks propagation in the TBM cutterhead have an important theoretical value and practical significance in improve the fatigue strength and accurately predict the crack propagation of the TBM cutterhead. (See Fig. 2.)

So far, scholars have improved the structure design of the TBM cutterhead by studying the rock fragmentation mechanism, cutterhead coupling layout, Cutter arrangement, dynamic modeling of cutterhead and the evaluation of the cutting efficiency [4–8]. However, there are few studies on the fatigue life prediction of TBM cutterhead, mainly focused on the static finite element simulation and the derivation of theoretical formula of single crack [9], The mechanism of crack damage and the rule of multiple crack propagation of TBM cutterhead have hardly been reported.In the field of simulation and theoretical calculation of multiple crack propagation, Kamaya [10, 11] considered that the multiple cracks can be equivalent to a single crack in the same region, which is the same as that proposed by the Murakami et al. in the early time [12]. Cannizzaro et al. [13] gived the closed form and stress field of crack tip for circular arch multiple cracks.Pang et al. [14]in view of the welding structure, the crack closure effect and the crack polymerization effect were taken into consideration for the welded structures, and the theoretical calculation model of crack propagation was established to predict the fatigue life of multiple cracks in welded structures. Lepore M et al. [15] simulate multiple three-dimensional crack propagation in a welded structure, based on a finite element approach by considering temperature dependent elastic-plastic material properties.Seifi et al. [16] through the comparison and analysis of the experimental and numerical calculation of the aluminum alloy hole plate with multiple site damages (MSD), explored the diameter of the hole, the thickness of the plate and the distance between the hole and the hole, and the path of the crack propagation path of the multi crack hole plate. Galatolo [17] studied the multiple crack propagation of the aircraft porous plate structure, establishes a theoretical prediction model, and uses the experiment to verify the correctness of the theoretical model. Jin et al. [18] proved the difference in the form of single crack and multiple crack propagation through experiments, and introduced the parameter Delta k-n to calculate the interaction of cracks in the common thread.; Dündar et al. [19] through fracture crack propagation analysis system (FCPAS) with finite element software, based on the plate with four hybrid crack, with a central hole and three crack plate and plate with three holes and four crack three different forms of the planar crack plate structure, the experiment of FCPAS analysis result with a large number of literature data, results show that the crack propagation path and the stress intensity factor respect is very precise, which confirmed FCPAS can very good use in predicting the plane crack plate structure crack propagation behavior. Trollé et al. [20] used the extended finite element method to simulate the expansion of two-dimensional rail multi-crack, and analyzed the influence of plastic stress on crack propagation path and stress intensity factor. Sutula D et al. [21] used the principle of minimum total energy to the problem of arbitrary crack growth in 2D. Zhu S P et al. [22] established a probabilistic framework for multiaxial LCF assessment of notched components by using the Chaboche plasticity model and Fatemi-Socie criterion. Qian G et al. [23] research work the effect of

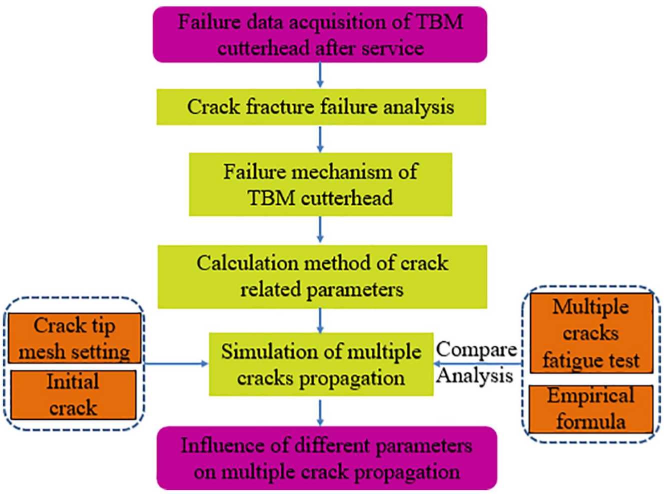

Fig. 2. The overall flow chart.