IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 13 February 2024, accepted 2 March 2024, date of publication 5 March 2024, date of current version 14 March 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3373896

RESEARCH ARTICLE

Critical Plane Methodology for Intelligent Prediction of Fretting Fatigue Lifetime Based on Shear Strain Dynamics

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This work was supported in part by Zhejiang Provincial Administration for Market Regulation Research Project of China under Grant ZC2021B091, and in part by Quzhou Science and Technology Key Project of China through ANSYS software under Grant 2023K247 and Grant 2023K044.

ABSTRACT An approach based on refined critical plane methodology to fretting fatigue lifetime prediction for structures was proposed. A new shear stress-strain interaction (SSI) critical plane equation is developed, predicated on shear strain energy for predicting fretting fatigue lifetime. In order to obtain the fretting fatigue lifetime quickly and intelligently, the SSI critical plane method intelligent prediction software was developed using the Newton-Raphson iteration method. To corroborate the utility of the SSI critical plane method, we conducted a fretting fatigue lifetime test and then compared the calculated results of the SSI fretting fatigue lifetime prediction and traditional SWT prediction with the experimental values. The results indicate that SSI fretting fatigue lifetime prediction is closer to the experimental results than SWT.

INDEX TERMS SSI critical plane method, fretting fatigue lifetime, intelligent prediction, shear strain dynamics.

I. INTRODUCTION

Fretting fatigue refers to the fatigue strength and life strength of components during fretting wear [1], which can promote the early initiation and accelerated expansion of fatigue cracks, finally leading to the failure of components considerably below the fatigue limit of materials or even below the elastic limit of materials, such as the fracture failure of bolt joints, tenon joints, riveting joints, hoisting ropes, etc.

The universality of fretting fatigue and the seriousness of its harm have attracted the attention of researchers worldwide, and the prediction of fatigue life has become a research hotspot [2], [3], [4], [5], [6], [7], [8], [9], [10].

Lykins, Szolwinski and Farris proposed the critical plane method of shear stress range (MSR) [11], [12], modified Smith-Watson-Topper (SWT) [13] and Findley (F) [14] parameters to predict the fretting fatigue lifetime when they is studying the fretting sphere model. A.Zabala and Magd Abdel Wahab use the theory of critical distance with mesh control approach are applied to predict the fretting fatigue lifetime [15], [16], [17], [18].

Thanh Q. Nguyen presents a new perception in evaluating fretting fatigue damage nucleation and propagation lifetime under periodically forced circulation by measuring the central point of power spectral density (CP-PSD) change in different structural stiffness degradation stages [19]. Some scholars also put forward the Continuum Damage Mechanics (CDM) approach in conjunction with Finite Element Method (FEM) to predict the fretting fatigue lifetime [20], [21], [22], [23],

The associate editor coordinating the review of this manuscript and approving it for publication was Jingang Jiang.

[24], [25]. Grzegorz Glodek proposed a simplified method to predict the fretting fatigue lifetime based on the concept of fretting fatigue damage stress combined with Continuum Damage Mechanics (CDM) [26], [27], [28].

In recent years, with the development of computing, some scholars have used big data and neural network methods to predict the fretting fatigue lifetime [29], [30], [31]. Sutao Han et al. used deep neural network combined with Findley parameters to predict the fretting fatigue lifetime to improve the prediction accuracy of the fretting fatigue lifetime [32], [33], [34].

However, Findley parameter is semi-empirical formulas that can be fitted from the actual ordinary fatigue experimental data, and their universality is not strong. Therefore, this article proposes an improve critical plane method for predicting the lifetime of fretting fatigue crack based on shear strain. This approach underscores that fluctuations in maximum shear strain energy can lead to the generation of fretting fatigue cracks. This is one of the energy methods in fretting fatigue lifetime prediction, which does not need more fatigue experimental data. In order to improve prediction accuracy, intelligent prediction software has been developed in this article.The prediction of fretting fatigue lifetime based on intelligent prediction of shear strain energy critical plane method is put forward in this paper, which has a certain significance for preventing catastrophic accidents caused by fretting fatigue in practical engineering.

II. FRETTING FATIGUE LIFETIME PREDICTION METHOD HAS BEEN DEVELOPED

A. SWT CRITICAL PLANE METHOD

SWT was a method for predicting fretting fatigue proposed by Smith-Watson-Topper [13]. The formula for predicting fretting fatigue is shown in Equation 1.

$$SWT = \sigma_{\max}\Delta\varepsilon_a = \frac{(\sigma_f^{'})^2}{E}(2N_f)^{2b} + \sigma_f^{'}\varepsilon_f^{\prime}(2N_f)^{b+c} \quad (1)$$

where $\Delta\varepsilon_a$ denotes the maximum value of the strain amplitude difference under the effect of maximum and minimum loads, and $\sigma_{\max}$ represents the maximum stress value on the plane with the maximum $\Delta\varepsilon_a$ value. $\sigma_f^{\prime}$, $\varepsilon_f^{\prime}$,b and C are material characteristics under cyclic tension and compression, $\sigma_f^{\prime}$ is fatigue strength coefficient,b is fatigue strength factor, $\varepsilon_f^{\prime}$ is fatigue toughness coefficient, and c is fatigue toughness factor, $2N_f$ is the cycle of fatigue failures.

The material characteristics of No. 45 steel under cyclic tension and compression [36] and its values is shown in Table 1.

TABLE 1. Material properties of steel No. 45 under cyclic tension and compression.

$\sigma_f^{'}$	$\varepsilon_f^{'}$	b	c
899.50	0.3269	-0.1047	-0.5485

B. FINDLEY CRITICAL PLANE METHOD

Parameter F was proposed by Findley WN [14]. This parameter includes the influence of shear stress and normal stress on fretting fatigue crack, which is shown in Equation 2.

$$F = \Delta\tau + k_1 \cdot \sigma_n^{\max} \quad (2)$$

where

$$\frac{k_1}{\sqrt{1+k_1^2}} = \frac{2\tau_{f-1}}{\sigma_{f-1}} - 1 \quad (3)$$

After obtaining the Findley parameter, the fretting fatigue crack initiation lifetime Ni could be calculated by using the following Equation:

$$F = \tau_f(2N_i)^{b'} \quad (4)$$

where k1 is a material constant, σ_{f-1} and τ_{f-1} represent the ratio of fatigue limit in tension and torsion, respectively, and τ_f is the shear fatigue strength coefficient, and b' represents the fatigue strength exponent in torsion.

C. CDM PREDICTION METHOD

CDM was proposed by Kachanov [37], and Bhattacharya [38] adopted the CDM method for fatigue and fretting fatigue problems. On the CDM, the most critical parameter to determine the crack initiation point in fretting fatigue condition is the equivalent multiaxial stress (σ^*), which can be estimated by von-Mises equivalent stress (σ_{eq}) and triaxiality function (R_v):

$$\sigma^* = \sigma_{eq}(R_v)^{\frac{1}{2}} \quad (5)$$

where

$$R_v = \frac{2}{3}(1+\nu) + 3(1-2\nu)\left(\frac{\sigma_H}{\sigma_{eq}}\right)^2 \quad (6)$$

Herein, σ_H is the hydrostatic stress, ν is Poisson's ratio.

The relationship between damage parameter, D, and number of cycles, N, is presented in equation 7 as:

$$\frac{\partial D}{\partial N} = A\frac{(\sigma_{eq,\max}^{\beta+2} - \sigma_{eq,\min}^{\beta+2})}{(1-D)^{\beta+2}} R_v^{(\frac{\beta}{2})+1} \quad (7)$$

where A and β is material constants, which can be estimated by regression method combined with experimental results and numerical data, $\sigma_{eq,\max}$ and $\sigma_{eq,\min}$ are the maximum and minimum von Mises stresses.

So, the damage variable can be expressed as:

$$D = 1-[1-A(\beta+3)(\sigma_{eq,\max}^{\beta+2}-\sigma_{eq,\min}^{\beta+2})R_v^{(\frac{\beta}{2})+1}N]^{\frac{1}{(\beta+3)}} \quad (8)$$

$$N = N_i \rightarrow D = 1 \quad (9)$$

And when the condition is as follows:

$$N_{\mathrm{i}} = \frac{1}{A(\beta+3)}(\sigma_{eq,\max}^{\beta+2} - \sigma_{eq,\min}^{\beta+2})^{-1} R_v^{-(\frac{\beta}{2})-1} \quad (10)$$

Then, equation 10 will be applied to determine the crack initiation lifetime.

III. SSI CRITICAL PLANE FRETTING FATIGUE LIFETIME PREDICTION METHOD IS PROPOSED

Brown and Miller [35] proposed that cyclic shear strain is the leading cause of crack initiation in multi-axial fatigue, and cyclic normal strain is the leading cause of crack propagation. According to the theory of Brown and Miller, cyclic shear strain is the leading cause of crack initiation, and cyclic normal strain is the leading cause of crack propagation. For the fretting fatigue failure process, fretting crack initiation accounts for about 89% of the failure process, and the crack propagation to failure only accounts for about 11%. Therefore, the crack initiation stage can be conservatively regarded as the whole failure process of the sample in the prediction process. According to the above theory, fretting fatigue crack initiation is mainly caused by the cycle of maximum and minimum shear strain, and the fluctuation of maximum shear strain energy is the leading cause of fretting fatigue crack initiation at the maximum shear plane. Based on this, the SSI critical plane method is proposed to determine the location and direction of fretting crack initiation.

A. FRETTING FATIGUE LIFETIME PREDICTION METHOD BASED ON SSI CRITICAL PLANE

Zhou proposed the SSI critical plane method for predicting fretting fatigue crack initiation [39]; It can be conceptualized as the product of the maximum shear strain energy and the maximum shear strain occurring on the critical plane, as follows:

$$SSI = \frac{\Delta\gamma}{2}\tau_{\max} \tag{11}$$

where $\Delta\gamma$ is the shear strain difference between the maximum load and minimum load, $\tau_{\max}$ is the maximum shear stress in the critical plane.

Building upon the earlier proposition that the initial crack emerges on the plane characterized by the maximum shear, it can be inferred that the plane exhibiting the most extensive range of shear strain is the locus of crack initiation and progression, expressed as follows:

$$\frac{\Delta\gamma}{2} = \frac{\tau_f}{G}(2\mathrm{N}_f)^{b'} + \gamma_f'(2\mathrm{N}_f)^{c'} \tag{12}$$

Furthermore, a maximum shear stress is introduced here to account for the effect of average stress, which can be determined from the shear form of the Coffin-Manson equation, which is given by:

$$\frac{\Delta\gamma}{2}\tau_{\max} = \frac{(\tau_f)^2}{G}(2\mathrm{N}_f)^{2b'} + \tau_f'\gamma_f'(2\mathrm{N}_f)^{b'+c'} \tag{13}$$

where τ_f', r_f', b', c' are material characteristics under cyclic torsion, τ_f' is fatigue strength coefficient, r_f' is fatigue toughness coefficient, b' is fatigue strength factor, c' is fatigue toughness factor, G is the shear modulus,, $2N_f$ is the cycle of fatigue failures.

According to the material of the sample in this test, it is No. 45 steel. The material characteristics of No. 45 steel under cyclic torsion [36] and its values is shown in Table 2, where G is 79GPa.

TABLE 2. The material characteristics of No. 45 steel under cyclic torsion and its values.

τ_f'	γ_f'	b'	c'
559.0	0.4959	-0.1079	-0.4690

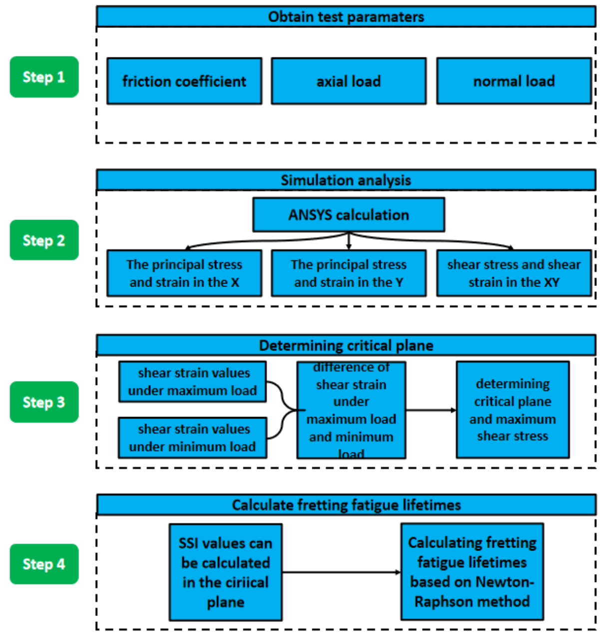

FIGURE 1. The algorithmic framework of the SSI critical plane method.

B. INTELLIGENT PREDICTION OF FRETTING FATIGUE LIFETIME

In order to realize an intelligent prediction of the fretting fatigue lifetime, this section proposes a fretting fatigue lifetime prediction based on the SSI critical plane method. The algorithmic framework of the proposed SSI plane method is shown in Figure 1 and the lifetimes prediction algorithm process is shown in Algorithm 1.

Step 1: Obtain experimental parameter

Call ANSYS software and call APDL program, read the experimental parameters such as friction coefficient, axial load, and normal load;

Step 2: Simulation analysis

Call APDL program, calculations the principal stress and strain in the X, Y direction, the shear stress and shear strain in the XY direction;

Step 3: Determining critical plane

3.1 Respectively calculate the shear the shear strains values under maximum load and minimum load, the calculation formula of $\gamma_{\theta 1\max}$ and $\gamma_{\theta 1\min}$ is as follows:

$$\begin{bmatrix} \gamma_{\theta 1\max} & \gamma_{\theta 1\min} \end{bmatrix} = \begin{bmatrix} \varepsilon_{x1\max} & \varepsilon_{y1\max} & \varepsilon_{x1y1\max} \\ \varepsilon_{x1\min} & \varepsilon_{y1\min} & \varepsilon_{x1y1\min} \end{bmatrix} \begin{bmatrix} \sin 2\theta 1 \\ -\sin 2\theta 1 \\ \cos 2\theta 1 \end{bmatrix} \tag{14}$$

Calculate the difference between shear strain values under maximum load and minimum load, and the calculation formula is as follows:

$$f(\gamma) = \gamma_{\theta 1\,\max} - \gamma_{\theta 1\,\min} \quad -90^\circ \leq \theta 1 \leq 90^\circ \tag{15}$$

3.2 The maximum difference of shear strain values is calculated. The calculation formula is as follows:

$$\gamma_{\max} = \max(f(r)) \tag{16}$$

3.3 The Angle at which the most significant difference in shear strain values is θ:

$$\theta = \theta_1 \tag{17}$$

The plane of the maximum value calculated according to equation 19 is determined as the critical plane, and finally, the maximum shear stress under the critical plane is calculated. The calculation formula is as follows:

$$\begin{bmatrix} \tau_{\theta\,\max} & \tau_{\theta\,\min} \end{bmatrix} = \begin{bmatrix} \sigma_{x\,\max} & \sigma_{y\,\max} & \tau_{xy\,\max} \\ \sigma_{x\,\min} & \sigma_{y\,\min} & \tau_{xy\,\min} \end{bmatrix} \begin{bmatrix} \frac{\sin 2\theta}{2} \\ -\frac{\sin 2\theta}{2} \\ -\cos 2\theta \end{bmatrix} \tag{18}$$

Step 4: Calculate fretting fatigue lifetimes

SSI values can be calculated from the determined critical plane, and the lifetime prediction of fretting fatigue is calculated according to the Newton-Raphson method. The calculation steps are as follows:

$$f(x) = \frac{(\tau_f)^2}{G}(2N_f)^{2b'} + \tau_f'\gamma_f'(2N_f)^{b'+c'} - \frac{\Delta\gamma}{2}\tau_{\max} \tag{19}$$

$$f(N_f) = \frac{(\tau_f)^2}{G}(2N_f)^{2b'} + \tau_f'\gamma_f'(2N_f)^{b'+c'} \tag{20}$$

$$f'(N_f) = 2b'\frac{(\tau_f)^2}{G}(2N_f)^{2b'-1} + (b' + C')\tau_f'\gamma_f'(2N_f)^{b'+c'-1} \tag{21}$$

$$f(x+1) = f(x) - \frac{f(N_f)}{f'(N_f)} \tag{22}$$

When the difference between the two is greater than 10^{-2}, convergence is obtained and calculation is stopped.

IV. FRETTING FATIGUE EXPERIMENT

The sample base material is 45 steel with a diameter of 10mm. Two parallel planes are processed on both sides, with a length of 180mm, a thickness of 8mm, and a standard distance of 48mm, as shown in Figure 2. The size of the fretting bridge is 32mm, the height is 10mm, the length of the fretting bridge is 4mm, the height is 2mm, and the thickness is 8mm, as shown in Figure 3. All samples were sanded with Grade 4 (1/0, 2/0, 3/0, and 4/0) sandpaper and cleaned with acetone solution. Ensure that the residual polishing marks follow the length of the specimen. The fretting bridge is made of the same material 45 steel and the same conditions.

Algorithm 1 A Fretting Fatigue Lifetimes Prediction Method Based On SSI Critical Plane

Input: Experimental parameters such as friction coefficient, axial load and normal load

Output: Prediction of fretting fatigue lifetimes

Step 2: Simulation analysis

Call APDL program, calculates the principal stress and strains in the X, Y direction, the shear stress and shear strain in the XY direction;

Step 3: Determining critical plane

3.1 Based on Equation 14, the shear strain under maximum load and minimum load are calculated respectively, and the difference of corresponding shear strain values is obtained based on Equation 15;

3.2 Based on Equation 16, the maximum difference of shear strain values is calculated;

3.3 Based on Equation 17, the Angle at which the maximum difference in shear strain range is obtained is identified as θ, and the plane on which θ lies is determined to be the critical plane. Then, maximum shear stress is calculated based on Equation 18.

Step 4: Calculate the lifetimes of fretting fatigue.

SSI values can be calculated from the determined critical plane, and the lifetime prediction of retting fatigue is calculated based on Equation 19-22, which is according to the Newton-Raphson method; when the difference between the two is greater than 10^{-2}, convergence is obtained and calculation is stopped.

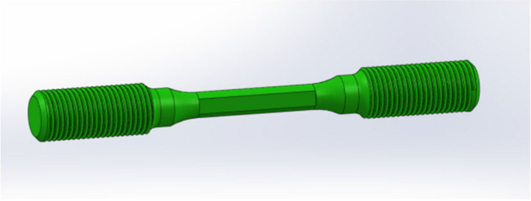

FIGURE 2. Diagram of fretting fatigue sample.

FIGURE 3. Structure diagram of fretting pad.

This experiment adopts a set of devices to simulate the fretting fatigue conditions, including a loading ring and a pair of bridges fretting pads. The experimental devices are shown in Figure 4. The two fretting bridges are symmetrically pressed on two parallel planes of the sample to form face-to-face contact. The lower end of the sample is fixed, and elastic elongation and recovery is generated under the action of the lower sinusoidal cyclic alternating tension so that the fretting

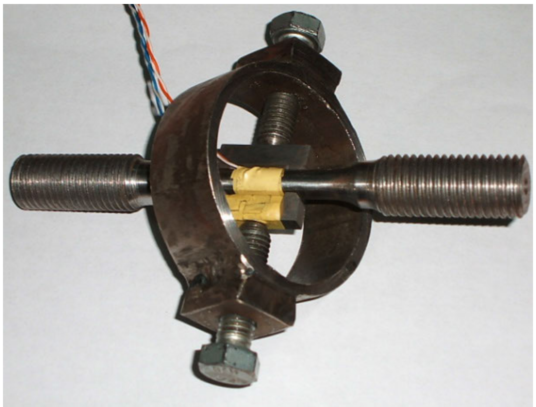

FIGURE 4. Fretting fatigue experiment device assembly.

FIGURE 5. General view of fretting fatigue experiment.

pad, which sums to the center of the sample, is symmetric between the fretting pad. The fretting amplitude is adjusted by changing the axial stress amplitude or changing the vertical load on the fretting pad, and the positive pressure is applied to the fretting block through the loading ring.

The experiment was carried out on the microcomputer-controlled electro-hydraulic servo static–dynamic material testing machine EHFED250kN-40L manufactured by Shimazu Company in Japan, Zhejiang University of Technology, as shown in Figure 5. The fretting fatigue frequency is 15Hz, and the stress ratio is 0. Seven different axial loads $\left(\sigma_y = 240, 280, 320, 360, 400, 440\, and\, 480MPa\right)$ were tested under one vertical load.

Fretting fatigue tests were carried out on a total of 28 samples in this experiment, and the fretting fatigue lifetime results under various loads were obtained, as shown in Table 3.

In the Table 3, $\sigma_{\max}$ is maximum axial load, $\sigma_{\min}$ is minimum axial load,and S_a is average axial load,cycle means a cycle of fatigue failures. In the sample of 1,5,9,13,17,21,25 the normal stress is 30MPa, the sample of 2,6,10,14,18,22,26 the normal stress is 60MPa, the sample

TABLE 3. Fretting fatigue lifetimes under various load conditions.

ID	$\sigma_{\max}$ / MPa	$\sigma_{\min}$ / MPa	S_a / MPa	Cycle
1	233.7	0.19	116.755	2945615#
2	237.9	0.37	118.765	2548913#
3	242.6	0.42	121.09	2353780#
4	244.9	0.73	122.085	1372200
5	283.5	0.91	141.295	2967813#
6	284.1	1.72	141.19	2156284#
7	282.9	-1.58	142.24	1557150#
8	279.6	0.28	139.66	111745
9	318.3	0.37	158.965	480189
10	319.4	-0.18	159.79	1093600
11	320.8	0.29	160.255	10936
12	321.7	0.84	160.43	364001
13	359.3	-0.49	179.895	666827
14	358.4	0.37	179.015	417727
15	362.1	-0.75	181.425	293343
16	361.8	0.91	180.445	245081
17	400.2	0.63	199.785	65003*
18	400.9	0.69	200.105	81143
19	402.7	0.74	200.98	76418
20	399.9	0.17	199.865	67005
21	439.8	0.85	219.475	71457
22	442.0	0.71	220.645	35121*
23	441.7	0.28	220.71	39517
24	438.9	0.25	219.325	38619*
25	479.8	1.20	239.3	330881*
26	479.3	0.09	239.605	13568*
27	481.1	-0.37	240.735	24793*
28	480.9	0.55	240.175	8245*

Note: # indicates that no failure occurred during shutdown;

* indicates that the leading edge does not occur at the contact point between the fretting bridge and the sample.

of 3,7,11,15,19,23,27 the normal stress is 90MPa, the sample of 4,8,12,16,20,24,28the normal stress is 120MPa

V. CALCULATION RESULTS AND ANALYSIS

A. FRETTING BRIDGE MODEL

The fretting bridge model is shown in Figure 3. The fretting bridge and sample material are steel 45#, with an elastic modulus of 210MPa and Poisson's ratio of 0.3.

The model's symmetry with respect to the X and Y axes allows for the analysis of only a quarter of the model. The simulation employs the face-to-face contact method within ANSYS finite software for computation. As the material of the fretting bridge matches that of the sample, a flexible-to-flexible contact nonlinear simulation method is chosen. The model utilizes plane82 elements, with the contact surface divided into ''conta172'' elements and the target surface into ''targe169'' elements.

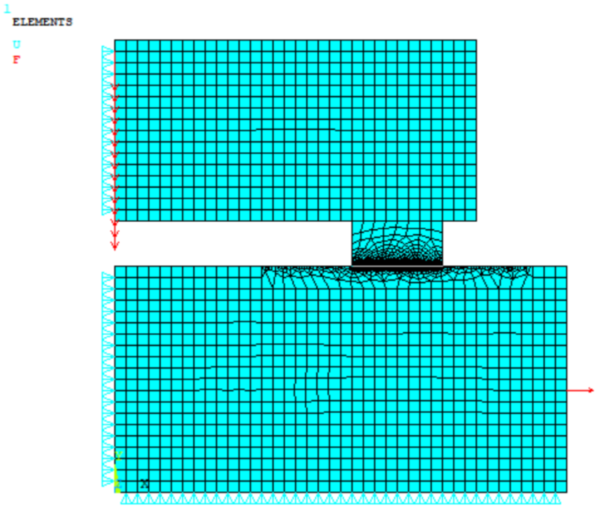

FIGURE 6. **Fretting bridge finite element loading diagram.**

Drawing from the insights of previous researchers, it is established that mesh refinement is essential in the contact region between the fretting bridge and the sample. Mesh sizes smaller than 10 μm are deemed sufficient for this purpose [40], [41]. Consequently, a finite element mesh with a size of 6 μm is chosen for the contact part. This involves quadrilateral mesh division in the contact area and free mesh division in the transition area, ensuring both computational precision and a manageable computational load. The mesh model encompasses a total of 29,636 nodes and 30,146 elements, including 1,000 contact elements and 800 target elements. The load graph of fretting bridge element analysis is shown in Figure 6.

B. RESULTS

The calculated stress values for normal loads of 1440N and axial loads of 0, 240, and 480MPa are shown in Figure 7. The Figure represents the tensile stress in the x direction, the normal stress in the y direction, and the tangential stress, and W denotes the width of the bridge foot. The calculation results indicate that the contact surface is completely in a cohesive state when there is a smaller contact load. The fully adhered to contact surface begins localizing as the cyclic axial load increases.

The occurrence of local sliding is due to the different distribution of normal σ_y and tangential stresses τ_{xy} on the contact surface. When $\sigma_y < \tau_{xy}$, it's the adhesive zone in the contact surface, then $\sigma_y \geq \tau_{xy}$ sliding is occurred in the contact surface. The distribution curves of normal stress σ_y and tangential stress τ_{xy} are shown in Figure 7 (a)-(b). At the low σ_A,the distribution of σ_y is mainly due to the effect of normal load. Maximum σ_y appears at the contact edge, and the σ_y of outer edge should be larger than the inner edge. In the middle, σ_y is a parabolic shape.

As the cyclic axial load σ_A increases, both σ_y and τ_{xy} increase at the inner end, decrease at the outer end, and slightly open at the outer end to form an open zone. As the cyclic load further increases, the adhesive zone continues to decrease, and the sliding zone and open zone continue to increase. The open zone is the effect of eccentric torque caused by the nominal contact pressure P on the left contact edge. From Figure 7 (b), it can be seen that the tangential

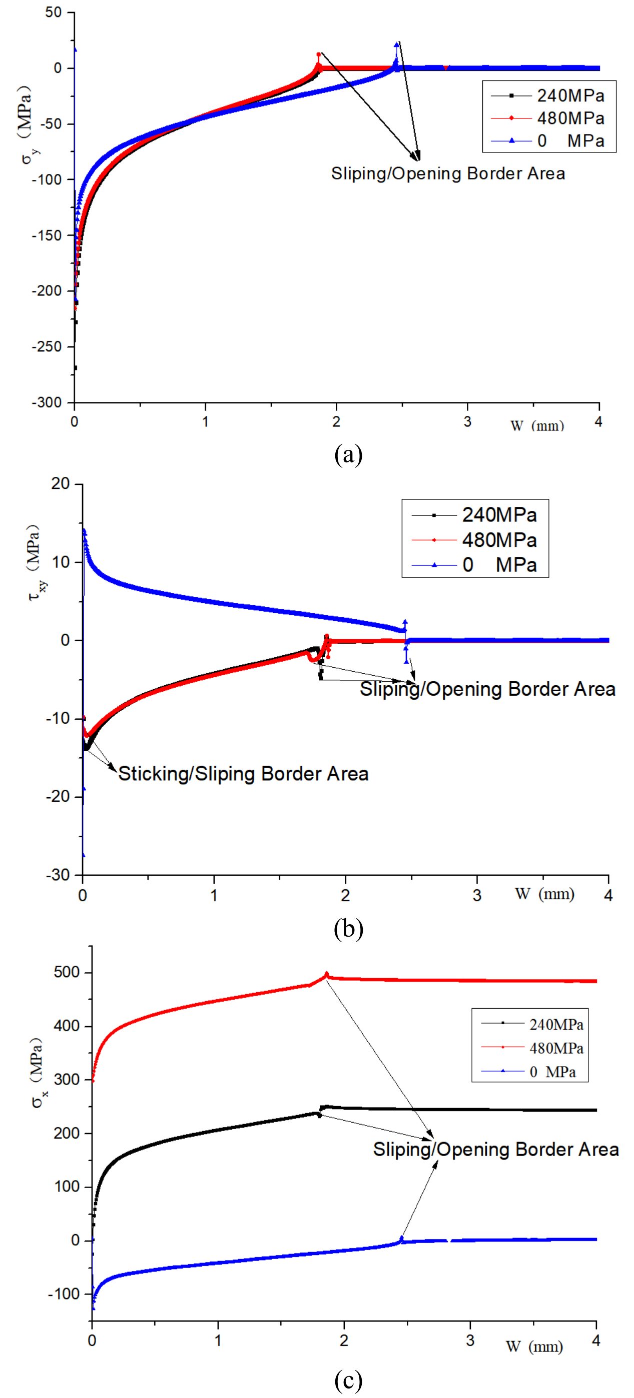

FIGURE 7. **Different stress distribution along the width of the bridge foot: (a) Normal stress distribution along the width of the bridge foot; (b) Tangential stress distribution along the width of the bridge foot; (c) Tensile stress distribution along the width of the bridge foot.**

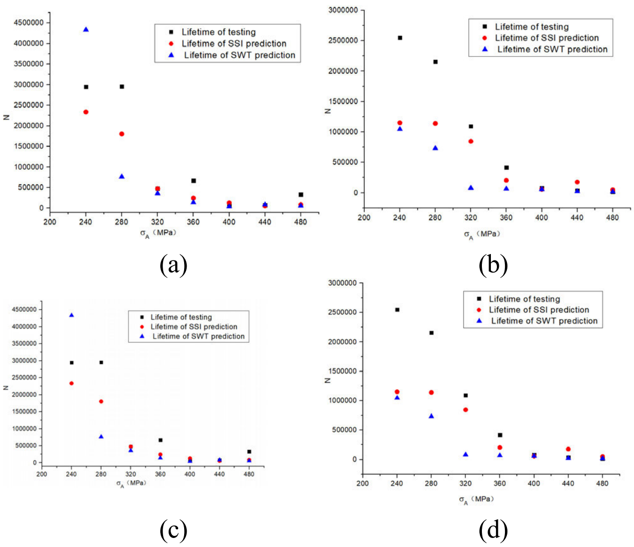

FIGURE 8. **The results under various normal pressures: (a) The normal pressure is 30MPa; (b) The normal pressure is 60MPa; (c) The normal pressure is 90MPa; (d) The normal pressure is 120MPa.**

force undergoes a sudden change in the adhesive/slip interface area and the slip/open interface area. This means that stress concentration occurs in these areas, and the wear is severe, making it easy to generate cracks in these areas. This is consistent with the experimental results.

C. PREDICTION RESULTS OF FRETTING FATIGUE LIFETIME

The comparison between the intelligent prediction using SSI and SWT and the experimental results is shown in Figure 8, where N represents the number of cycles and σ_A represents the axial stress.

Of course, due to the large dispersion of fretting fatigue tests, it is normal for individual data not to match. After analysis, the inconsistent data were all caused by accidental factors and have been removed. These data are four sets of values obtained when the normal stress is 30MPa, the axial stress is 400MPa, the normal stress is 60MPa, the axial stress is 440MPa, the normal stress is 90MPa, the axial stress is 320MPa, and the normal stress is 120MPa, the axial stress is 280MPa.

Figure 8 show that predicting the life of fretting fatigue using SSI and SWT is relatively close. However, there are still significant errors in a few samples. For example, when the normal pressure is 120MPa, and the axial stress is 280MPa, the predicted value using SSI for this sample is much larger than the experimental value. This is mainly related to factors such as the preparation of the sample during the test process and the specific operation of the test. However, overall, the predicted value of the SSI method is lower than the experimental value. In practical engineering, using the SSI method to predict the structure's fatigue life can ensure the structure's safe use within its actual life and have a certain safety margin.

Figure 8 show that the predicted fretting fatigue lifetime using the SSI method is closer to the experimental fretting fatigue life value than the SWT method.

VI. CONCLUSION

(1) Founded on the theory that fluctuations in maximum shear strain energy are the primary causative factor behind the emergence of fretting fatigue cracks, we have introduced an enhanced SSI critical plane method for predicting fretting fatigue lifetime and a mathematical formula for predicting fretting fatigue life is derived.

(2) According to the formula for predicting the fretting fatigue lifetime using the SSI critical plane method, an intelligent prediction software for fretting fatigue life based on the SSI critical plane method was developed, achieving intelligent prediction of fretting fatigue lifetime.

(3) Establishing a fretting fatigue testing device, the fretting fatigue lifetime test was tested under various normal pressures and different axial loads.

(4) The SSI fretting fatigue lifetime intelligent prediction method was successfully used to calculating fretting fatigue lifetime, and the results were consistent with experimental values.

(5) In the fretting bridge model, it was found that the predicted fretting fatigue lifetime using the SSI method is closer to the experimental values than traditional SWT method.

(6) In the future, we will evaluate the feasibility of SSI method in predicting more fretting fatigue lifetime by establishing a fretting pad experimental model.

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