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Fatigue Crack Initiation (FCI) Life Prediction for a Flat Plate with a Central Hole

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ABSTRACT

This work constructs an effective procedure that combines the finite element and strain-life methods in order to accurately predict fatigue crack initiation (FCI) life and then establish an estimated schedule of fatigue life. The proposed method is applied to a flat plate with a central hole to obtain predicted lives. Comparing the results from the proposed method is compared with those of Juvinall's stress-life method, Socie's local strain method and Bannantine's summary experimental data. Comparative results demonstrate that the fatigue life estimated by the novel procedure closely approximates the experimental results.

Keywords：Notch, stress concentration, finite element method, crack initiation life.

1. Introduction

Fatigue life prediction for notched members may be approached from several viewpoints. For crack initiation, many researchers have supplemented the traditional approach, which is based on nominal stresses and stress concentration factors. Peterson [1] initially used elastic stress concentration factors and nominal stresses to estimate the fatigue lifetime of notched members, but the later studies [2-4] used the Neuber's rule [5,6], which uses the relations between nominal stresses and strains to estimate the fatigue life of the material at the notch root. The above analyses assumed the crack propagation part of fatigue life to be extremely small. Meanwhile, Socie [7] used local stress-strain concepts and a cumulative-damage approach to predict fatigue-crack initiation in engineering structures subjected to random loading, and Newport et al. [8] used Neuber's rule and the equivalent strain-energy density method to predict fatigue-crack-initiation life. Furthermore, Costa [9] predicted fatigue crack initiation life for notched bend specimens with two different notch acuities and two stress ratios using the equivalent strain energy density method, while Giglio and Vergani [10] employed total strain energy density numerically determined through elastic-plastic analysis to predict fatigue life. Yip et al. [11] investigated multi-axial fatigue crack initiation lives for solid cylindrical specimens with transverse circular holes.

This work constructs an effective procedure by combining the finite element and strain-life methods to predict fatigue crack initiation (FCI) life and then establishing an estimated fatigue life schedule. The proposed procedure can obtain the complete distribution of structural strains and strain-time history at the notch by using the finite element method, and can also obtain the fatigue life at any location in the structure by smooth specimens fatigue resistance. Additionally, this investigation considers interaction between loads, and Miner's rule can be used to calculate the cumulative damage in the FCI phase. The proposed procedure is then applied to a flat plate with a central hole, and the results compared with those of Juvinall's stress-life method, Socie's [7] local strain method, and Bannantine's summary experimental [13] data. Comparative results demonstrate that the fatigue life estimated by the novel procedure closely approximates experimental results.

2. Fatigue-analysis Procedure

The life prediction procedure involves two parts, as illustrated in Fig. 1. The structural analysis involves the stresses and strains calculated in a highly stressed area where slip concentrates from the input loads for a given material and geometry. The stresses and strains of critical areas are transformed into fatigue damage, and integrating the damage subjected to an empirical failure criterion produces a prediction for structural life.

In the structural analysis, the strains and stresses can be calculated at each time increment using a finite element method in which loading history is the input of the structural model. The service stress-strain field in these critical areas within the components can also be found by using the finite element method. The structural analysis assumed that the material followed the Von Mises yield criterion and the associated flow rules.

3. Analytical Model

To assess whether the use of the more accurate present calculation procedure improves fatigue-life prediction, predictions made with Juvinall's stress-life method, Socie's [7] local strain method and the method presented herein are compared with experimental results taken from Bannantine[13].

3.1 Specimen and material properties

The material used herein is medium strength steel [13], The length, width and thickness of the plate are assumed to be 1.00in, 10in and 0.30in, respectively, while the diameter of the central circle is 0.50in.

3.2 Finite element model for notched plates

This investigation develops a two-dimensional symmetrical plane stress model for converting a load-time history into a strain-time history by using the finite element method. The model employs two-dimensional four node plane elements. Figure 2 displays the finite element meshes for the notched plates, along with the refined meshes used in the stress concentration area. The symmetric model contains 280 elements and 339 nodes after meshing.

4.Results and Discussion

Stress acting along the loading direction is known as axial stress, and is denoted by σ_y. Figure 3 illustrates the contours of σ_y for load P=9.03 Kips. The critical areas of the stress-strain field of the notched plates were found by the finite element method. As Fig. 3 displays, a high tensile stress occurred at point 'a' along the central hole. Following analysis with the finite element method, specimens A-1~A-6 are into plastic scope while specimens A-7~A-10 remain in elastic scope. Figure 4 presents the cyclic stress-strain curve of specimens A-1~A-6 at point 'a', and Fig. 5 displays the strain-time history of specimens A-7~A-10 on point 'a'. Owing to hysteresis loops of specimens A-1~A-6 and the strain range of specimens A-7~A-10 having been determined, a fatigue life analysis for the amplitude history can be performed by using a strain life equation. Figure 6 presents the results of applying various techniques to predicting the endurance of the notch plates (specimen A) under zero mean loads, with the experimental lives being in terms of first crack (approx 0.02in). As Fig. 6 indicates, the prediction results obtained by the novel method showed a strong correlation with the experimental results.

5.Conclusion

1. The Juvinall's [24] stress-life method achieves the most accurate results for high cycle fatigue (HCF), where the notch strains are predominantly elastic and loading is essentially constant. This approach does not account for inelastic behavior at the notch and cannot properly account for changes in notch mean stresses.
2. The relatively conservative fatigue life estimates yielded by Socie's local strain method (Neuber's rule) result from over prediction of the notch strain in the notch tip.
3. Applying the approach method rather than Socie's and Juvinall's method leads to an improvement in improve fatigue-life predictions, and the predictions are equally accurate for both the low and high cycle fatigue-life regions.
4. The proposed life prediction procedure, which combines the finite element method (FEM) and convenient notch analysis, is presented herein. The suggested procedure is applied to various

specimens with different materials, geometries, and stress ratios, and the predictive results are successfully compared with experimental data.

Reference

1. Peterson, R. E. (1959) Technical Report 59-507, U.S. Air Force-WADC Symp. Fatigue Metals, Dayton, Ohio.
2. Topper, T. H., Wetzel, R. M., and Morrow, J. (1969) *J. Mater.*, Vol.4, No. 1, pp. 200-209.
3. Dabell, B. J., Hill, S. J., Eaton, D. E., Watson, P. (1977) *Journal of the Society of Environmental Engineers*, Vol. 16, No 4, Dec., pp. 3-11.
4. Truchon, M., ASTM STP 770, C. Amzallag, B. N. Leis, and P. Rabbe, Eds. (1982) *American Society for Testing and Materials*, pp. 254-268.
5. Neuber, H. (1946) Theory of Notch Stresses: Principle for Exact Stress Calculations, J. W. Edwards, Ann Arbor, Mich.
6. Neuber, H., J. (1961) *Appl. Mech, Trans. ASME,* Vol. E28, pp.544-560.
7. Socie, D. F. (1977) *Experimental Mechanics*, Vol. 17, Feb., pp. 50-56.
8. Newport, A., Glinka, G. (1990) *Experimental Mechanics*, Vol. 30, No. 2 Jun, pp. 208-216.
9. Costa, J.D.,Ferreira, J.M. (1993) *International Journal of Fatigue*, Vol. 15, No. 6, Nov, pp. 501-507.
10. Giglio, M., Vergani, L. (1995) *Journal of Engineering Materials and Technology*, Vol.117, Jan., pp. 50-55.
11. Yip, Ming-Chuen, Jen, Yi-Ming (1996) *International Journal of Fatigue*, Vol. 18, No. 2, pp. 111-117.
12. Juvinall, R. C. (1967) *Engineering Considerations of Stress, Strain and Strength*, McGraw-Hill, New York.
13. Bannantine, Julie A., Comer, Jess J. and Handrock, James L. (1990) Fundamentals of Metal Fatigue Analysis, Prentice Hall, Englewood Cliffs, New Jersey.

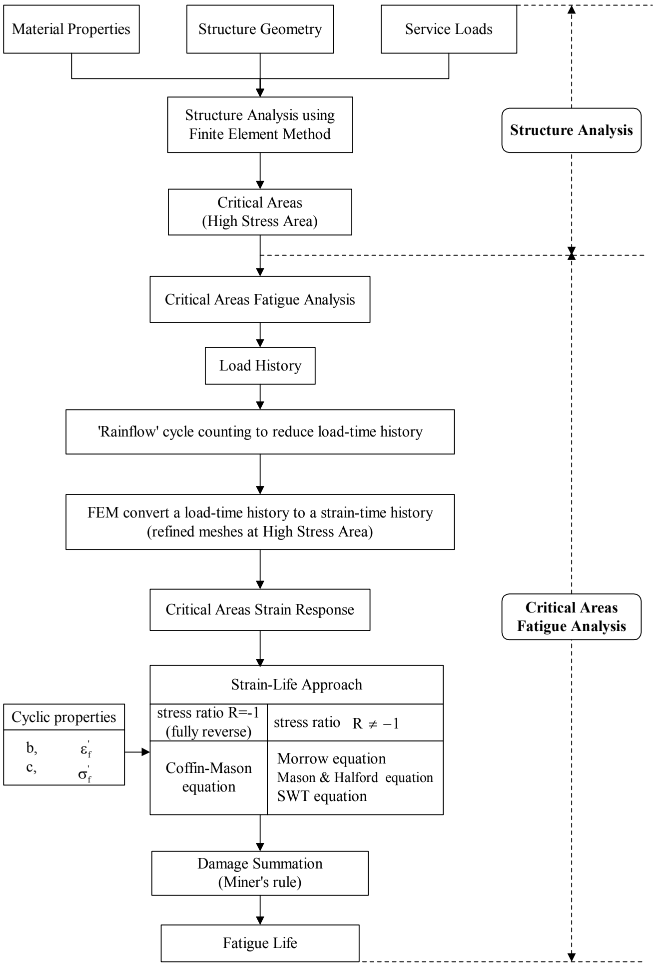

Figure 1: Life prediction flow chart

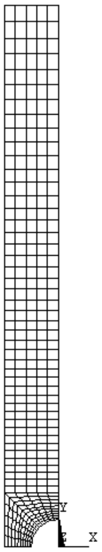

Figure 2: Refined mesh for the notched plates(325 elements)

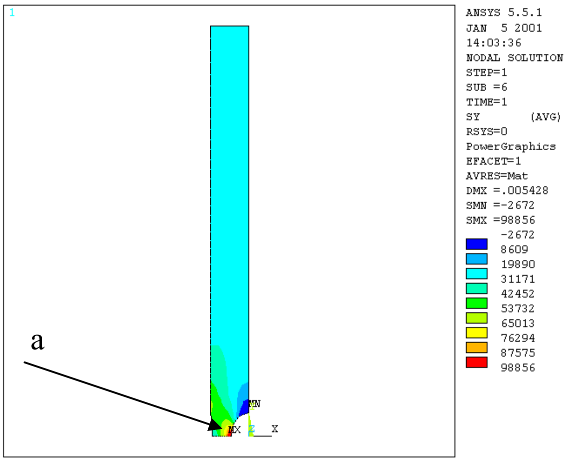

Figure 3: Contours of σ_y

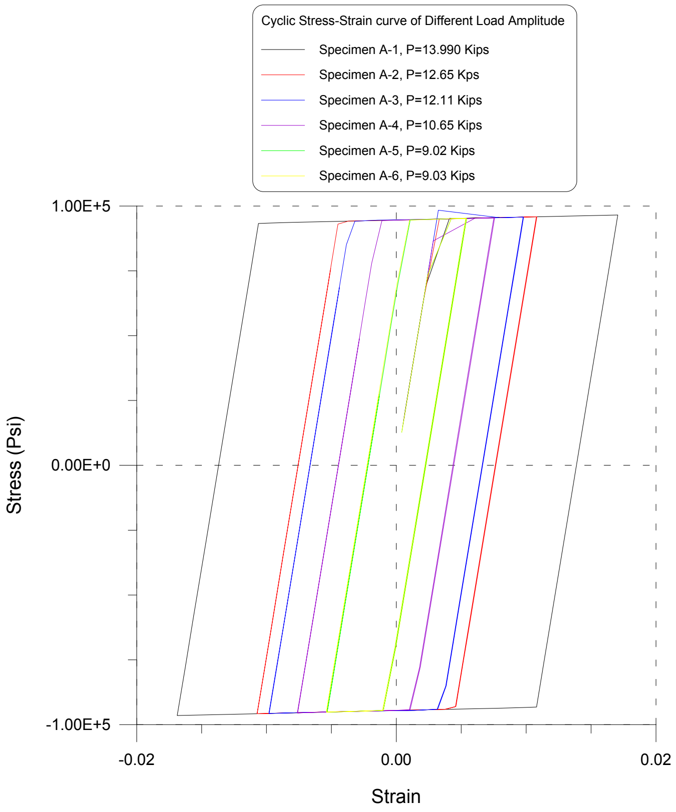

Figure 4: Cyclic stress-strain curve of specimen A-1~A-6

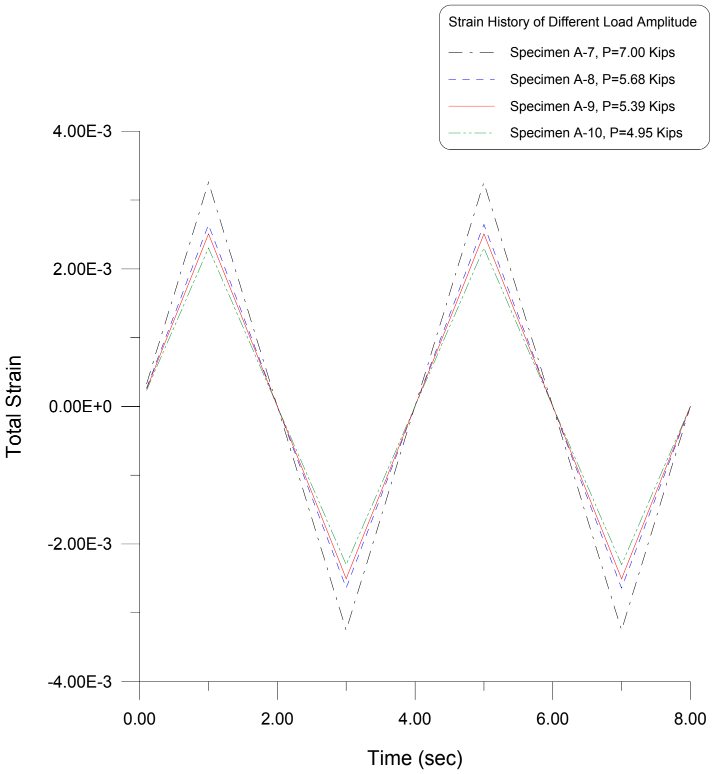

Figure 5: Strain-time history of specimen A-7~A-10

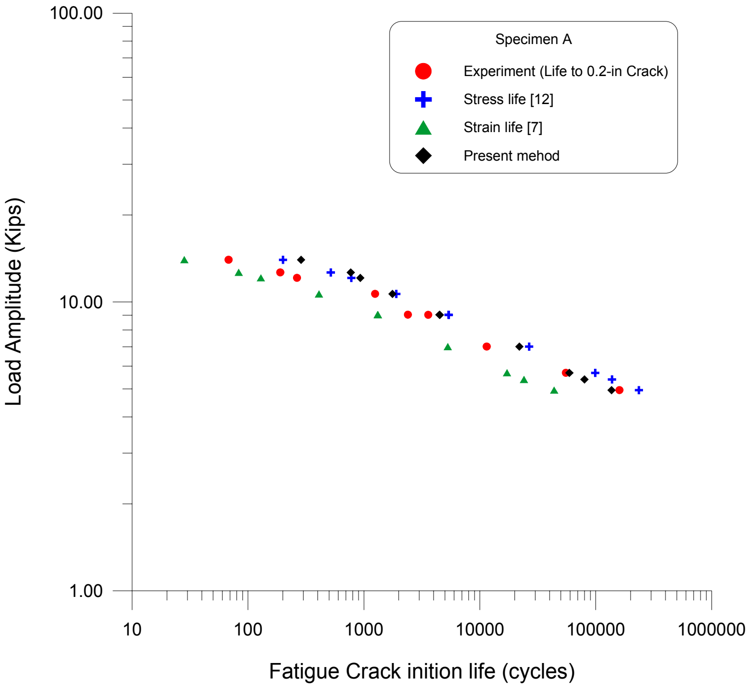

Figure 6: Various techniques for predicting the endurance of the notch plates (specimen A)