ISSN: 0973-3469, Vol.18, No.(2) 2021, Pg.

Material Science Research India

www.materialsciencejournal.org

Hydrostatic Stress and Fatigue Crack Growth of Notched Ti6Al4V In Aggressive Media

SERGIO BARAGETTI

Department of Management, Information and Production Engineering, University of Bergamo, Viale Marconi 5, 24044 Dalmine (BG), Italy.

Abstract

The behavior of structures, machine or components made of composite materials or light high-performance alloys is still a great concern for applications in which high strength-to-mas-ratio is a fundamental requirement. Procedures to detect flaws or small initial cracks and evaluate fatigue crack growth are nowadays essentials for high performance flying or ground machines (airplanes, automobiles,...). Structural reliability and structural health monitoring are considered in this paper and the surface replica method is deepened. Numerical FEM models were developed to assist the surface replica method analysis of the results.Ti6Al4V alloy was considered. This paper is a short technical communication.

Article History

Received: 24 April 2021

Accepted: 21 May 2021

Keywords

Crack Growth;

Corrosion;

Replica Method;

Ti6Al4V.

Introduction

This paper reports a procedure to evaluate crack propagation via the replica method and to calculate the multiaxial stress state influence at the crack tip via FEM numerical models.[1-4] Ti6Al4V alloy was considered. Structural reliability and health monitoring are studied in this paper and the surface replica method is deepened. Numerical FEM models were developed to assist the surface replica method analysis of the results. Surely the proposed procedure is not immediately applicable in situ (on flying airplanes or working machines): it is rather a laboratory procedure that can be applied in a restricted and controlled environment. The procedure is suitable for components or machines for which the safe-life approach is needed.

FE Fracture Mechanics Numerical Models

The stress concentration factor can be evaluated by means planar numerical models, either plane strain or with stresses lying in the plane. Lee[2] and Anderson[3] proposed equation (1) for the evaluation of the stress concentration factor (Figure 1):

$$K_I = \frac{E}{1+\nu}\sqrt{\frac{2\pi}{r}}\frac{u}{f(\theta)} \qquad f(\theta) = sin\left(\frac{\theta}{2}\right)\left[\kappa + 1 - 2\,cos^2\left(\frac{\theta}{2}\right)\right] \quad ...(1)$$

CONTACT Sergio Baragetti sergio.baragetti@unibg.it Department of Management, Information and Production Engineering, University of Bergamo, Viale Marconi 5, 24044 Dalmine (BG), Italy.

Doi:

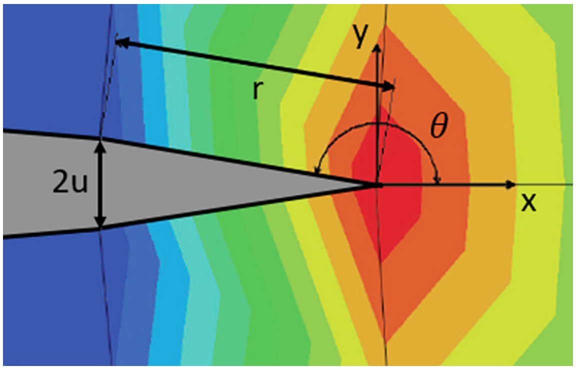

Fig. 1: crack tip behavior and useful parameters (adapted from ref. 9)

with u CTOD (crack opening displ.);

$\kappa = 3 - \nu / 1 + \nu$ for stresses lying on the plane.

Elastic perfectly-plastic of elastic plastic-hardening numerical finite elements models should be developed. Accuracy of the numerical grid refinement at the stress concentration area is fundamental, along with the simulation of the non-linear behavior of the material.

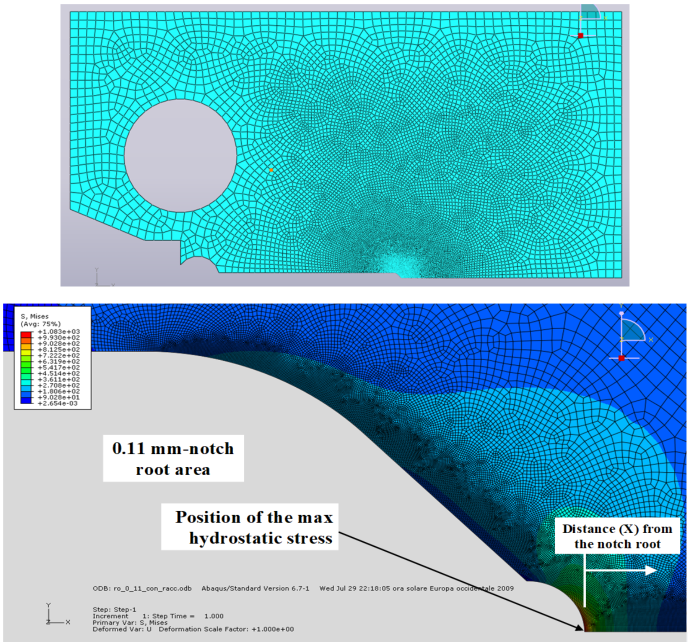

Fig. 2: examples of the grid accuracy at the notched area

Fatigue crack propagation can be monitored via the replica method and modelled via numerical finite element modelling. The use of an optical or a stereoscopic microscope can help in observing crack propagation detected by using the replica method.

Defect propagation is allowed only when the limit stress intensity factor range ΔK_{IC} is reached. Many literature models can be used, as reported in equations.[2-4] All the cited equations were developed from theories in which a linear elastic behavior of the material is taken into account.

Paris[5] $$da / dN = C(\Delta K)^n \qquad ...(2)$$

Walker[6] $$\frac{da}{dN} = \frac{C_1}{(1-R)^{m_1(1-\gamma)}} \Delta K^{m_1} \qquad ...(3)$$

Kato *et al.*[7]

$$\frac{da}{dN} = \frac{C}{1-\rho^n}\left(\Delta K^n - \Delta K_{th}^n\right) \text{for} \Delta K_{th} < \Delta K < K_C$$

$$\frac{da}{dN} = \frac{C}{1-\rho^n}\left(\frac{\Delta K^n \Delta K_{IC}^n}{\Delta K_{IC}^n - \Delta K^n}\right) \text{for} K_C < \Delta K < K_{IC}$$

...(4)

Material parameters useful for equations (2-4) can be found in the literature for many materials. Surely for steel, Titanium and Aluminum alloys.

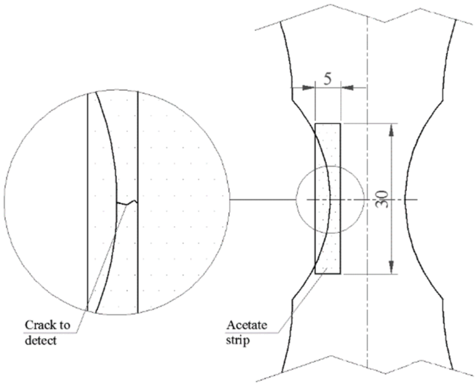

Fig.4: acetate strip put over the damaged cracked area of the component (adapted from ref. 9)

Experimental Validation of the Results: The Surface Replica Method

The behavior at the defect gage section can be monitored by using a certain kind of "negative image" of the damaged surface. Researchers can use acetate strips having small thickness (in the range 0,1-0,2 mm). Acetate strips have to be immerged in acetone for a few seconds and then accurately pressed on the damaged surface (Figures 4 and 5).

(a) (b)

Fig. 5: the researcher takes the "negative replica" image of the damaged surface (adapted from ref. 9)

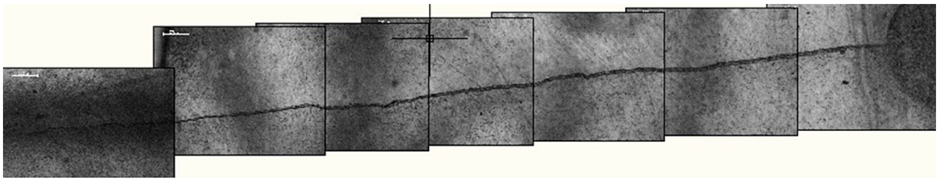

Fig. 6: "negative images" of the damaged surface. Images taken with a optical or stereoscopic microscope (adapted from ref. 9)

Figure 6 shows some “negative images” of the damaged surface. Images taken with a optical or stereoscopic microscope.

Conclusions

This paper is a short technical communication in which a procedure to evaluate crack propagation via the replica method and to calculate the multiaxial stress state influence at the crack tip via FEM numerical models was reported. Ti6Al4V alloy was considered. Structural reliability and health monitoring were studied in this paper and the surface replica method was deepened. Numerical FEM models were developed to assist the surface replica method analysis of the results. The procedure is suitable for components or machines for which the safe-life approach is needed. Laboratory environment is required to apply the procedure.

Acknowledgements

The author would like to thank the reviewers for their helpful comments and constructive suggestions that greatly improved the paper.

Funding

This research received no specific grant from any funding agency.

Conflict of Interest

The author has no conflicts of interest to disclose.

References

1. Baragetti, S., Villa, F., 2015. “Quasi-Static Behavior of Notched Ti-6Al-4V Specimens in Water-Methanol Solution”. *Corrosion Reviews,* 33, 6.
2. Anderson, T.L., 2005. Fracture Mechanics, third ed., Taylor & Francis, Boca Raton.
3. Baragetti, S., Villa, F.; 2015. High-Strength Titanium Alloys Under Different Stress Gradients. *The Journal of The Minerals, Metals & Materials Society* (JOM), 67, 5.
4. Baragetti, S., Villa, F., 2014. SCC and corrosion fatigue characterization of a Ti-6Al-4V alloy in a corrosive environment – experiments and numerical models. Frat. Integrità Strutt., vol. 8, no. 30, pp. 84–9
5. Anderson, T.L., 2005. Fracture Mechanics, third ed., Taylor & Francis, Boca Raton.
6. Beden, S.M., Abdullah, S., Ariffin, A.K., 2009. Review of Fatigue Crack Propagation Models for Metallic Components, *Eur.J. Sci. Res.,* 3, 364–397.
7. Kato, M., Deng, G., Inoue, K., Takatsu, N., 1993. Evaluation of the Strength of Carburized Spur Gear Teeth Based on Fracture Mechanics, *JSME Int. J., Ser. C,* 36(2), 233–240.
8. Beden, S.M., Abdullah, S., Ariffin, A.K., 2009. Review of Fatigue Crack Propagation Models for Metallic Components, *Eur.J. Sci. Res.,* 3, 364–397.
9. Baragetti, S., 2019. Numerical Simulation of Defects and Inclusions in Materials and Components, *Evolution in Polymer Technology Journal*, Vol. 2, Issue 3.