Numerical Simulation of Defects and Inclusions in Materials and Components

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Abstract

This paper reports methods and equipment needed to forecast the time, or number of cycles, to failure or break a component via FE fracture mechanics models and confirmation of the results through experimental procedures. Today engineers have powerful tools that allow designing any machine component made of any kind of material via Laptop, using commercial FE codes, and simple laboratory tests for verification (i.e surface replica method).
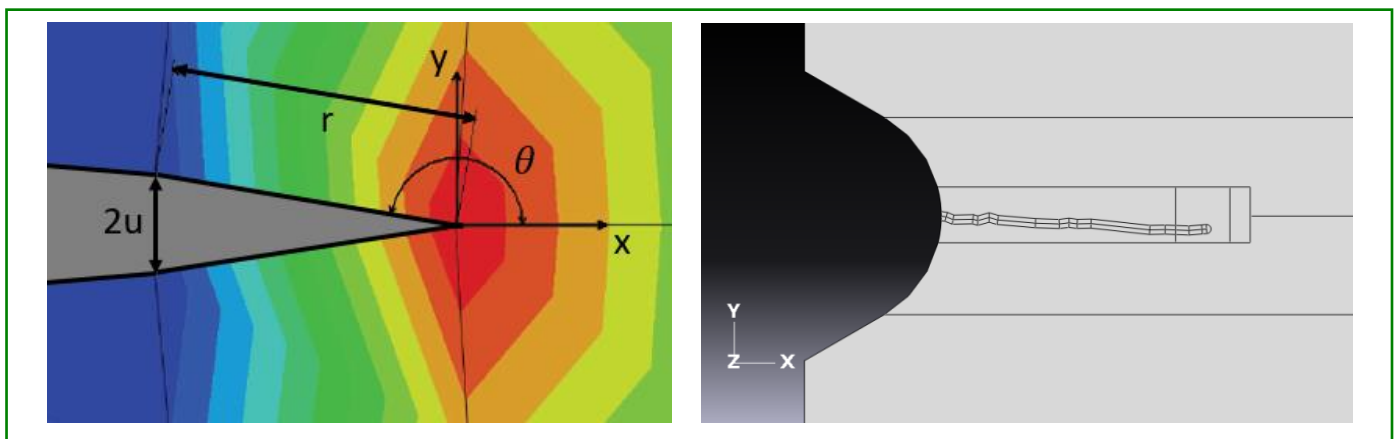
FE Fracture Mechanics Analysis

The K_t (stress concentration factor) values for different notches of components can be calculated by 2D linear elastic FE modeling with plane-stress elements [1] and quadratic shape functions, based on Lee *et al.* [2]. K_I (Stress intensity factor) can be calculated by means of the model presented by Anderson [3]:

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

With u is the half crack tip opening displacement; $\kappa = \frac{3-v}{1+v}$ for plane stress configuration.

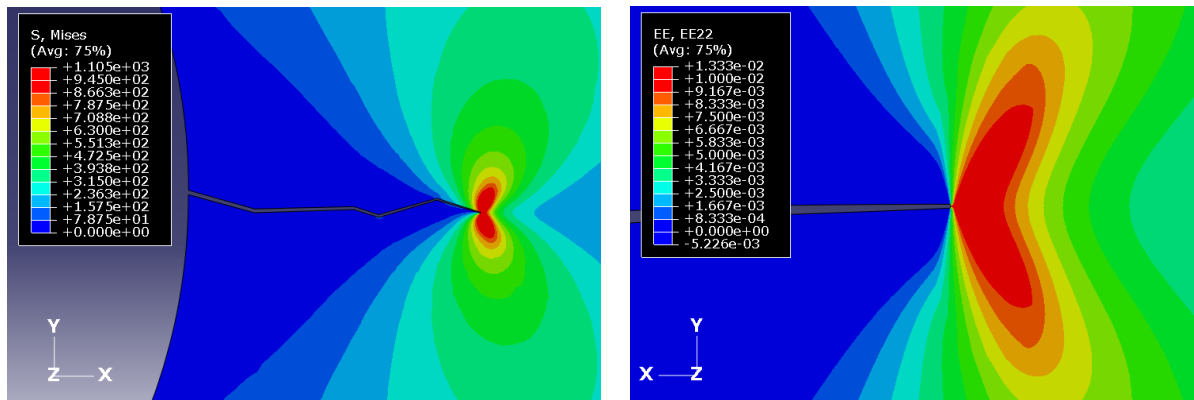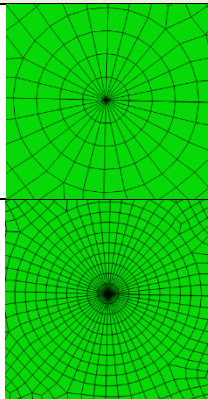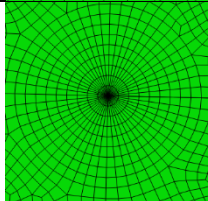The crack paths can be simulated to reproduce the ones pointed out with the replica microscope observations.

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Figure 1: FE model for crack propagation [4].

The crack propagation can modeled with finite increments until K_{IC} (threshold stress intensity factor, with depends on the material) can be find in the literature and ΔK can be obtained by linear extrapolation of the K_I values on the crack tip. Elastic behavior can be assumed, even though small plasticization may occur. Three propagation laws can be considered:

- Paris [2] $\frac{da}{dN} = C(\Delta K)^n$ (2)

- Walker [5] $\frac{da}{dN} = \frac{C_1}{(1-R)^{m_1(1-\gamma)}} \Delta K^{m_1}$ (3)

- Kato et al. [6]

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

$$\frac{da}{dN} = \frac{C}{1-\rho^n}\left(\frac{\Delta K^n \Delta K_{IC}^n}{\Delta K_{IC}^n - \Delta K^n}\right) \text{ for } K_C < \Delta K < K_{IC}$$ (4)

The constants values can be found in the literature. Kato model describes better the growth phase while Walker law gives a more suitable correlation than Paris.

Table 1 reports some of the results a commercial FE code can give: elastic deformation EE2 in load direction, plastic deformation PE22 in load direction, hydrostatic stress and Equivalent Plastic Deformation PEEQ at a specified depth (3.2 µm in this example) behind the crack tip calculated with differently sized elements at the crack tip in the final crack configuration (Ti6Al4V specimens), [6].

Mesh quality	Element size [µm]	Mesh counter at the crack tip area	Axial elastic strain (EE2) at a depth of 3.2 µm behind the crack tip	Axial plastic strain (PE22) at a depth of 3.2 µm behind the crack tip	Hydrostatic stress [MPa] at a depth of 3.2 µm behind the crack tip	Equivalent plastic strain (PEEQ) at a depth of 3.2 µm behind the crack tip
1	2.0		8.99E-3	6.41E-1	947	7.94E-1
2	1.0		8.46E-3	9.82E-1	818	1.24
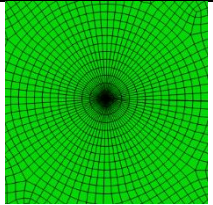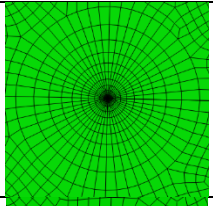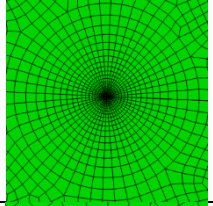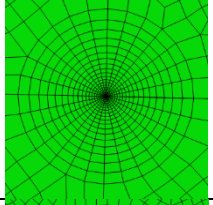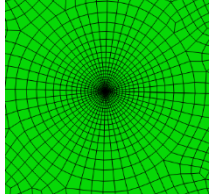
3	0.70		8.29E-3	1.06	764	1.33
4	0.34		8.08E-3	0.99	783	1.41
5	0.11		7.92E-3	0.99	767	1.59
6	**0.1**		**7.79E-3**	**0.84**	**823**	**1.40**
7	0.08		7.79E-3	0.96	767	1.6

Table 1: EE2, PE22, hydrostatic stress and PEEQ at a depth of 3.2 μm behind the crack tip calculated with differently sized elements at the crack tip in the final crack configuration (Ti6Al4V specimens), [6].

Experimental Validation of the Results: The Surface Replica Method

The features at the gage section can be controlled during the tests by means of the survace replica method. The replica material is acetate in sheets with a thickness of the order of a few tenths of a μm. Small strips (5 mm x 30 mm) of acetate were used to cover the area of interest in the way shown in 2.

Before placing an acetate strip over the notch tip area it had to be softened with acetone by immersion for about 5 seconds. Both the dimensions of the strips and the time of immersion were calibrated to prevent the risk of oversized deformations and bulging of the replicas after complete evaporation of the solvent. After immersion the strips were firmly pressed into position on the polished metal surface.
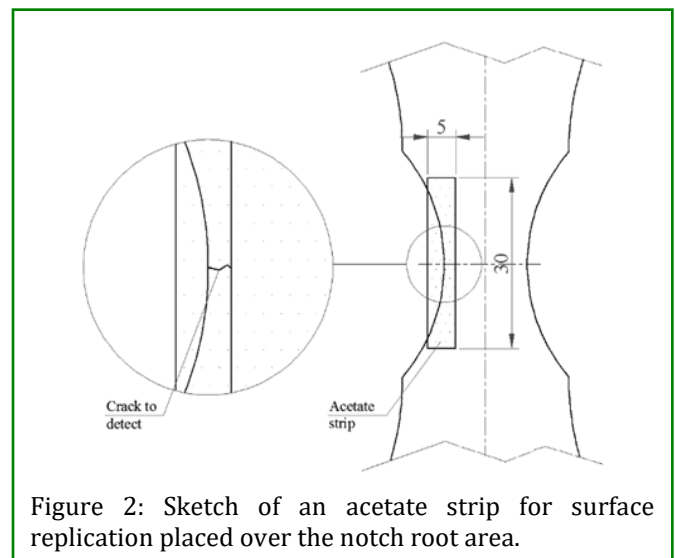

Figure 2: Sketch of an acetate strip for surface replication placed over the notch root area.

Careful preparation of the surface to be investigated was necessary to produce replicas suitable for showing all the features accurately. The replicas were kept laid over the gage area for at least 20 seconds to let the soft acetate penetrate into the voids present on the surface so that the image of possible cracks could be captured. Then the replicas were carefully removed from the metal surface and left in a safe place until full evaporation of the solvent. Each replica (Figure 3) has to be labeled and sent for optical microscope observation (i.e. LEICA OPTO43 – 112401 optical microscopes).

(a)

(b)

(c)

(d)

Figure 3: Surface replication procedure:
a) Immersion of an acetate strip in acetone for few seconds.
b) Positioning of the strip over the notch tip area.
c) The strip is firmly pressed on the sample surface.
d) Then removed to let the solvent evaporate.
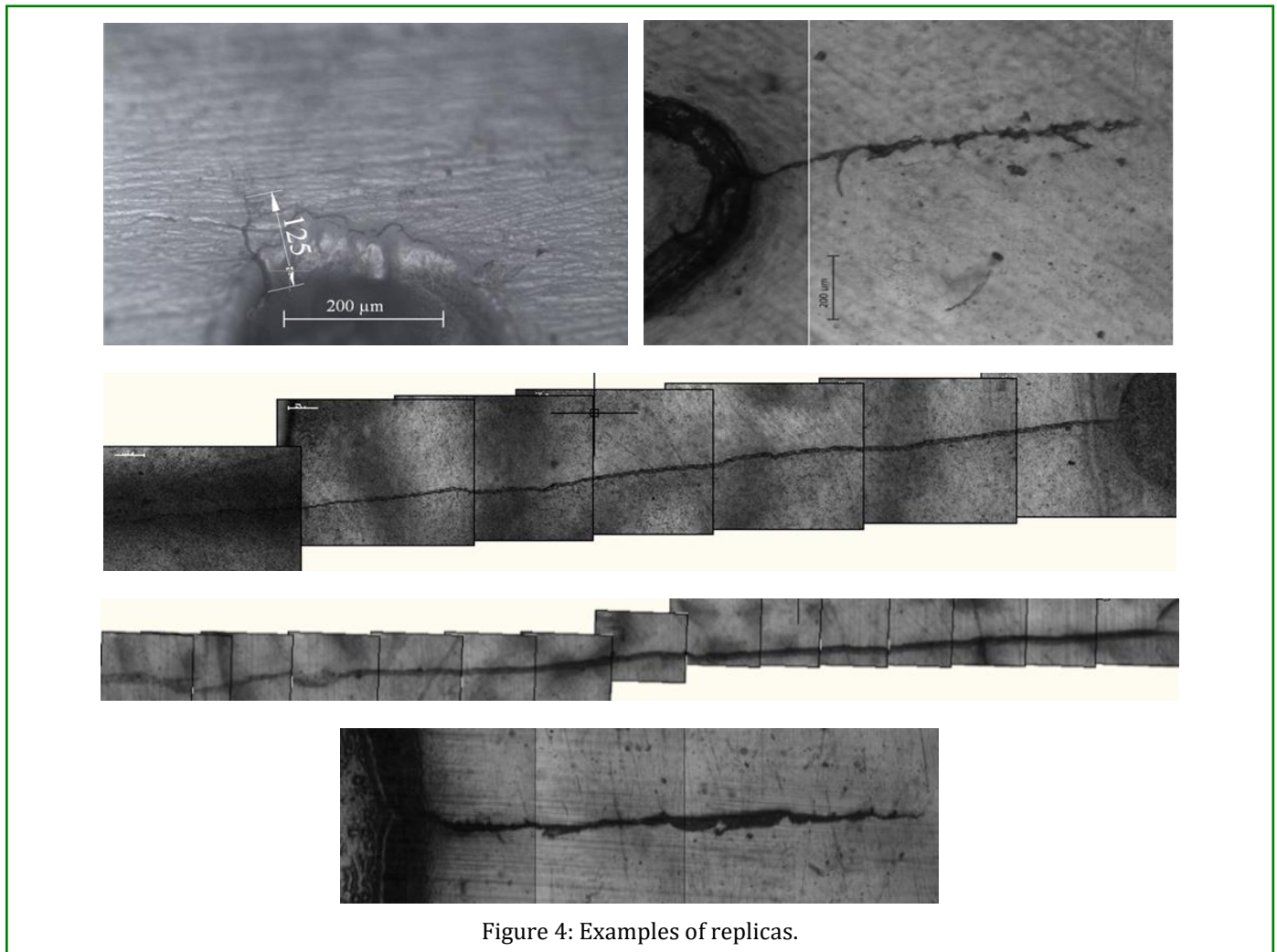
Figure 4 shows some examples of replicas.

Figure 4: Examples of replicas.

Conclusion

A Theoretical, FE numerical and experimental procedure was presented in this paper. The procedure allows predicting the applied stress and number of cycles for the complete rupture of a component made of any kind of material. The procedure can be used also for a safe-life approach, for which monitoring the crack propagation rate is fundamental. The surface replica method was used to confirm the results.

References

1. Baragetti S, Villa F, Gerosa R (2015) Quasi-Static Behavior of Notched Ti-6Al-4V Specimens in Water-Methanol Solution. Corrosion Reviews.

2. Anderson TL (2005) Fracture Mechanics. (3rd edn), Taylor & Francis, Boca Raton, CRC Press.

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): 1154-1161.

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 ed Integrità Strutt 8(30): 84-89.

5. Beden SM, Abdullah S, Ariffin AK (2009) Review of Fatigue Crack Propagation Models for Metallic Components. Eur J Sci Res 28(3): 364-397.

6. 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.