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Procedia Structural Integrity 8 (2018) 433–443

Structural Integrity Procedia

www.elsevier.com/locate/procedia

AIAS 2017 International Conference on Stress Analysis, AIAS 2017, 6-9 September 2017, Pisa, Italy

Radial basis functions mesh morphing for the analysis of cracks propagation

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Abstract

Damage tolerant design requires the implementation of effective tools for fracture mechanics analysis suitable for complex shaped components. FEM methods are very well consolidated in this field and reliable procedures for the strength assessment of cracked parts are daily used in many industrial fields. Nevertheless the generation of the computational grid of the cracked part and its update after a certain evolution are still a challenging part of the computational workflow. Mesh morphing, that consists in the repositioning of nodal locations without changing the topology of the mesh, can be a meaningful answer to this problem as it allows the mesh updating without the need of rebuilding it from scratch. Fast Radial Basis Functions (RBF) can be used as an effective tool for enabling mesh morphing on very large meshes that are typically used in advanced industrial applications (many millions of nodes). The applicability of this concept is demonstrated in this paper exploiting state of the art tools for FEA (ANSYS Mechanical) and for advanced mesh morphing (RBF Morph ACT Extension). Proposed method is benchmarked using as a reference a circular notched bar with a surface defect. Reliability of fracture parameter extraction on the morphed mesh is first verified using as a reference literature data and ANSYS Mechanical tools based on re-meshing: different crack shapes are achieved using the new geometry as a morphing target. Crack propagation workflow is then demonstrated showing the computed shape evolution for different size and shape of the initial crack.

Peer-review under responsibility of the Scientific Committee of AIAS 2017 International Conference on Stress Analysis

Keywords: RBF; Fracture Analysis; Notched Bars; Crack Growth; Mesh Morphing

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10.1016/j.prostr.2017.12.043

1. Introduction

It is well known that the fatigue life of a structural component copes with the initiation and propagation of a crack. Under cyclic loading, a flaw may appear on the surface of the material and progressively grow until its size becomes critical. On the other hand, singularities introduced in the shape of a structure are preferential sites of crack initiation. This is due to the local stress increase that they provoke and, possibly, to the surface damage that machining could have caused. It is thus reasonably that these two circumstances are supposed to work together. Several authors (Carpinteri et al. (2003), Lin and Smith (1998), Murakami (1986), Guo et al. (2003), Biancolini and Brutti (2002)) dealt with the issue of a notched round bar with a crack in the reduced cross-section. The Stress-Intensity Factors (SIFs) are deduced through a Finite Element (FE) approach, which can keep into account the influence of the notch on the crack. The fatigue propagation paths of the fracture can be determined by employing the Paris-Erdogan law (Paris and Erdogan (1963)). The shape of the crack front changes after each cyclic loading step, according to the current values of the SIFs. The study of the subsequent configurations that the crack assumes during its evolution is a challenging task (Galland et al. (2011)). Each advancement of the front entails an updating of the mesh, which can result annoying and rather time-consuming if led by hand. This last consideration suggests the idea that is at the basis of the present paper. Mesh morphing techniques (Staten et al. (2011), de Boer et Al. (2007), Biancolini (2011)) allow a fast arrangement of the existing mesh to a new configuration. This enables an implementation of design variations, which is much faster than re-meshing the entire body from scratch. A large number of different crack front geometries can be derived morphing a baseline configuration. Time spent to obtain the FE model would reduce drastically, and furthermore, the simulation of crack growth could be automatized through an analysis-and-update procedure. Many methods are actually available to put in practice the just described process. A rough distinction can be made upon the role played by the mesh: mesh morphing methods can be categorized as either mesh-based or mesh-less. Our choice fell on a meshless approach, in particular the one implemented by the tool RBFMorph^{TM}. Radial Basis Functions (RBF) constitute its mathematical background. They are real-valued functions, taken from the Approximation Theory. Some basic concepts about RBF are given in the next section. Mesh morphing based on RBF proved to give excellent results in many practical examples (Biancolini and Cella (2010), Biancolini and Groth (2014), Cella et al. (2017)). Its major drawback is that, despite its meshless working principle, element topology does not change during the morph operation. This last foresees a simple displacement of node locations and the extent of morph must take into account degeneration of mesh quality.

The activities presented in this work were financially supported by the RBF4CRACKS project funded by the University of Rome "Tor Vergata" under the program "Consolidate the Foundations".

Nomenclature

a	Crack depth
b	Semi span of the crack
CD	Circumferential Divisions: number of angular divisions of crack tube
D	Bar diameter in the un-notched cross section
D_0	Bar diameter in the notched cross section
F	Applied force to the bar
FE	Finite Element
FT	Fracture Tool
L	Bar length, L = 4D
LCR	Largest Contour Radius of wedge elements around the crack front
N_{cyc}	Number of cycles related to crack growth
RD	Radial Division of crack tube
RBF	Radial Basis Functions
α	Crack aspect ratio, $\alpha = a/b$
σ_F	Nominal tensile stress referred to the reduced cross-section
ζ	Curvilinear abscissa along the crack front