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Study of fatigue cracks with numerical and experimental methodsD. Camas^a, P. Lopez-Crespo^{a,*}, A. Gonzalez-Herrera^a, A. S. Cruces^a, B. Moreno^a*^aDepartment of Civil, Materials and Manufacturing Engineering, C/Doctor Ortiz Ramos, s/n,
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Abstract

Recent technological improvements in digital photography have made Digital Image Correlation (DIC) a robust and reliable technique for measuring displacement and strain fields at the surface of a cracked specimen. Bulk information can be extremely valuable to understand mechanisms such as crack closure or crack tunnelling that have a large impact on the fatigue crack growth. Displacement and strain information in the bulk is very difficult to obtain experimentally but can be obtained by numerical analysis such as Finite Element Method (FE). The current work presents a new methodology combining experimental DIC data with numerical results obtained from ultrafine 3D FEM modelling. The strain distribution around a fatigue crack in a wedge opening loaded specimen obtained with FEM is validated with experimental DIC data. In addition, the combination of both techniques is used to evaluate the effect of the crack front curvature.

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Keywords: Stress intensity factor; finite element method; digital image correlation; crack front curvature

1. Introduction

Since the development of computer calculation capacities, numerical methods have been extensively used to solve complex engineering problems as Fracture Mechanic ones. Nevertheless, these numerical solutions are subjected to a great number of uncertainties, so it is necessary to evaluate the quality of these solutions considering any validation process.

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Nomenclature

| | |
|--------------|--|
| a | specimen crack length |
| b | specimen thickness |
| c | cross-correlation product |
| $I(x,y)$ | matrix of intensity values depending on the coordinates of the pixel |
| N | size in pixels of the subregions |
| rpD | Dugdale's plastic size |
| (t_x, t_y) | vector which define the translation of the crack tip |
| u, v | horizontal and vertical distances between the centres of suregions |
| γ | rotation angle of the crack plane |

Mesh refinement studies, or error estimation techniques, can help to evaluate the quality of the numerical solutions. Nevertheless, uncertainties in the numerical modelling process are difficult to eliminate without comparing with experimental data. In the present paper a combined numerical-experimental approach is proposed and analysed in order to study a Fracture Mechanic problem. Finite Element (FE) is used as numerical method and digital image correlation (DIC) is applied to obtain a full image of the experimental displacement field at the surface level of the specimen. The comparison of both results provides the opportunity to validate the numerical model on the one hand, and to study specific issues of the problem on the other hand.

In recent years, DIC technique has matured into a stable and reliable method for measuring displacement and strain fields. In the last few years, this technique has started to be applied in the field of Linear Elastic Fracture Mechanics [1-3]. Full-field measurements constitute an opportunity to validate experimentally numerical simulations by direct displacement and strain comparisons. A validated finite element model provides much more information than experimental tests. This is the case of some three-dimensional effects of crack propagation which the classical Linear Elastic Fracture Mechanic theory avoids. Issues like the influence of the specimen thickness and the crack front curvature are not considered. These issues could influence the fatigue life of metallic materials strongly affected by crack closure effects [4]. Finite element methods allow the study of crack closure with great detail and can provide valuable information about the mechanisms involved in the bulk of the material in 2D and 3D cases [5-10]. Experimental investigation of such bulk mechanisms is possible [11, 12] but requires access to 3rd generation synchrotron facilities [13, 14]. Alternatively, the validation of FE results can be done with indirect measurement being under discussion [15].

In the present work, a methodology employing DIC experimental technique is presented in order to validate the results of previous FE studies [16, 17]. As a first step, it is employed to validate the distribution of stresses through the thickness of a cracked specimen when considering a straight crack front. Secondly, it is analysed the effect of the crack front curvature. It is proved a better correlation between the experimental DIC results and the FE ones when the crack front of the modelled specimen has some curvature. By means of this correlation, it was possible to estimate the presence and magnitude of this curvature.

2. Digital Image Correlation

A hybrid methodology combining experimental data and numerical analysis was employed for validating the finite element models. The approach consisted on four steps. Firstly, a series of images of the surface of the specimen were recorded with a digital camera. Cracked specimens subjected to different types of loads were employed in this step. Comparison of the images by means of a correlation algorithm allowed us to extract the displacement fields describing the behaviour at the surface [18, 19]. Subsequently, a dual use of these fields was made. On the one hand, an edge-finding routine was applied to the fields in order to extract the exact location of the crack tip [20]. On the other hand, a mathematical model based on linear elasticity was fitted to the experimental displacement fields [1-3]. This fitting required the crack tip coordinates inferred in the previous step. Finally, the stress intensity factor of the crack was extracted out of this fitting. Only the displacements fields and the crack tip coordinates will be used in the comparison with the numerical results. The rest of elements are mentioned for the sake of completeness.

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