CRACK PROPAGATION ANALYSIS OF ITER VACUUM VESSEL PORT STUB WITH RADIAL BASIS FUNCTIONS MESH MORPHING

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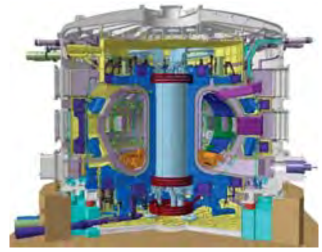
INTRODUCTION

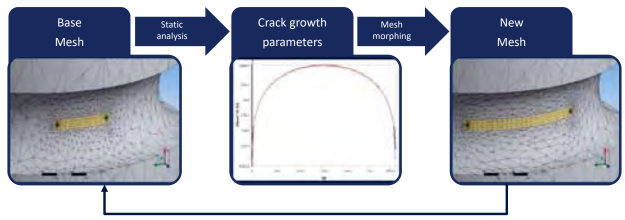
The **ITER Vacuum Vessel (VV)** is the sealed steel, torus shaped vacuum chamber that houses the plasma, made by 9 toroidal sectors (40° each). Its functions of first containment barrier against radiation and heat, provider of high quality vacuum, heat remover and support for in-vessel components make the structure one of the most important of the ITER machine.
The **severe operating conditions** of the tokamak impose the component to be designed to withstand strong dynamic loads. Due to the not total accessibility of the VV to **non-destructive examination (NDE)**, but also to identify the minimum safe dimension of defects embedded in the component, **RCC-MR nuclear code** gives useful guidelines for the verification of the design via **Fracture Mechanics (FM) analyses**.
A new method to evaluate the **crack shape evolution** during cyclic loadings has been developed. This method use **Finite Elements Analysis** in conjunction with **morphing techniques** for a fast arrangement of the existing mesh to a new configuration.



METHOD WORKFLOW

The method has been developed in **ANSYS Workbench** environment. The crack shape evolution has been computed using a **Multiple Degrees of Freedom (MDOF)** model with mesh update through **Radial Basis Function mesh morphing**.

- **Multiple degrees of freedom models:** divides the crack front into a set of points and defines the crack shape by connecting the points through cubic splines or simply through polygonal lines.
  - ➢ More precise crack shapes and fracture parameters
  - ➢ Can be used in complex scenarios, including mixed-mode loading and out of plane propagation
- **Mesh morphing techniques:** the update of the mesh can be achieved moving the nodes of a baseline configuration.
  - ➢ Reduced computational time
  - ➢ Possibility to automatize the process
  - ➢ Problems of mesh degeneration



VALIDATION WITH LITERATURE CASES

The method has been validated on **Lin and Smith** numerical model for the crack shape evolution tested on smooth and notched bars [1]. **Caspers** experimental results are also included [2].

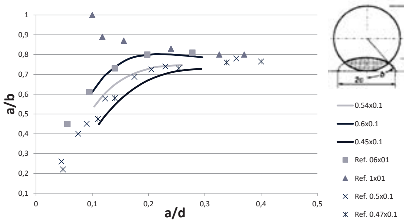
Smooth bar, semielliptical crack:

- a0/d = 0.1 , a0/b0 = 0.45 ;
- a0/d = 0.1 , a0/b0 = 0.54 ;
- a0/d = 0.1 , a0/b0 = 0.6 ;

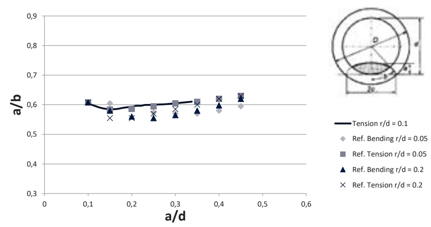
Notched bar, semielliptical crack:

- Notch ratio: r/D = 0.1;
- Crack: a0/D = 0.1; a0/c0 = 0.6;

Good agreement with the experimental results.



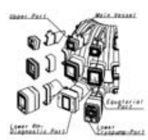
All geometries converge asymptotically to a **preferred pattern** as they extend. (a/b = 0.75)

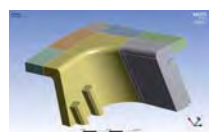


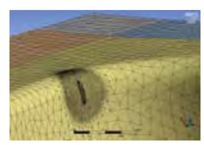
The shape development is not affected significantly by the notch ratio, r/d, and loading.

APPLICATION AND COMPARISON

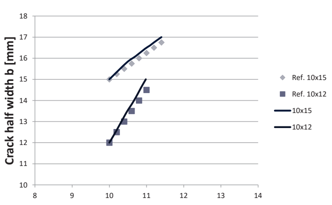
The method has been finally applied to a **local model** of one Vacuum Vessel port stub.
Results from the MDOF model are compared with the **Two Degrees of Freedom Model (2DOF)** used for the assessment.
The full load spectrum (combination of seismic, thermal, electro-magnetic events) has been taken into account by the use of **Miner rule** for cumulative damage, defining an equivalent cyclic load and number of cycles (estimated life of 7280 cycles) that produce the same damage in the flawed part.



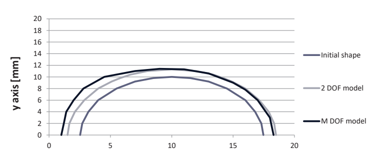


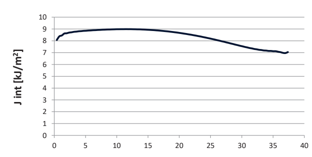


Not a significant difference can be spotted from the comparison of the crack geometrical parameters, since the crack shape changes during propagation are small.



The peculiarity of the multiple degrees of freedom model is clear when the entire crack is considered. The crack modelled by the MDOF procedure develops a **small asymmetry** with respect of the initial geometry.





Since the **crack is close to the smoothed edge** of the port stub, the fracture parameters curves are not symmetric, and so are not the crack increments computed for each node. This leads to a higher growth of the crack side close to the smoothed edge.

CONCLUSIONS

- ➢ A **new procedure** for the prediction of crack shape evolution has been **developed**, based on a **MDOF model** for the nodal crack front increments and on **mesh morphing** for a quick rearrangement of the mesh
- ➢ The method is in a **good agreement with the reference results** coming from other MDOF models, as long as with experimental results
- ➢ The method application shows the **differences in the approximation** introduced with the 2DOF models

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References:

[1] X. B. Lin, R. A. Smith, "Fatigue Growth Simulation for Cracks in Notched and Unnotched Round Bars"
[2] M. Caspers, C. Mattheck and D. Munz, "Propagation of surface cracks in notched and unnotched rods"