Fatigue crack growth under vibration load

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Abstract : *Since 2002, Cenaero has developed Morfeo/crack for fatigue crack growth analyses. Morfeo/Crack is based on the eXtended Finite Element Method (XFEM) and the level set techniques. Morfeo/Crack has been integrated as a plug-in for SAMCEF. The XFEM and level set method are now available in SAMCEF for 3D fracture mechanics problems. Consequently, 3D crack propagation analyses is made achievable inside a familiar environment for stress engineers. In this paper, the developed solution procedure is explained, and several benchmarks are detailled. It is shown how easy it is now to define a fracture mechanics problem and to simulate the crack propagation.*

Introduction

The eXtended Finite Element Method (XFEM) was introduced by Nicolas Moës in the late nineties [MOE99]. The main advantage of this method is to allow for modeling fracture crack growth problems while minimizing the remeshing operations. In the XFEM framework, a crack is not modeled by a mesh conformed to the crack faces but by modifying the displacement formulation using the dedicated enrichment functions and additional terms. Morfeo/crack is the fracture mechanics software developed by Cenaero since 2002. Morfeo implements the XFEM as well as the level set method [SET96] using dedicated crack growth algorithms [DUF07]. Based on this, three-dimensional crack growth analysis can be performed within a linear elastic fracture mechanics framework. Plug-in solutions of Morfeo/crack have been developed, among them the plug-in Morfeo/crack for Samcef offers the possibility to solve three-dimensional fracture mechanics problems in the same environment than the one used for stress analysis. The plug-in has been developed for ASEF and MECANO solvers.
The first section of this paper presents the description of the plug-in Morfeo/crack for Samcef. Validation cases are presented in the second section while an application which has been realized by Cenaero is presented in the last section.

The plug-in Morfeo/Crack for Samcef

The plug-in Morfeo/Crack for Samcef is based on a substructuring approach[WYA07, WYA07b]. The problem is decomposed into two regions:

– The FE (or uncracked) region which is handled by Samcef
– The XFE (or cracked) region which is handled by Morfeo

The XFE region is defined by a selection of elements which is represented in figure 1

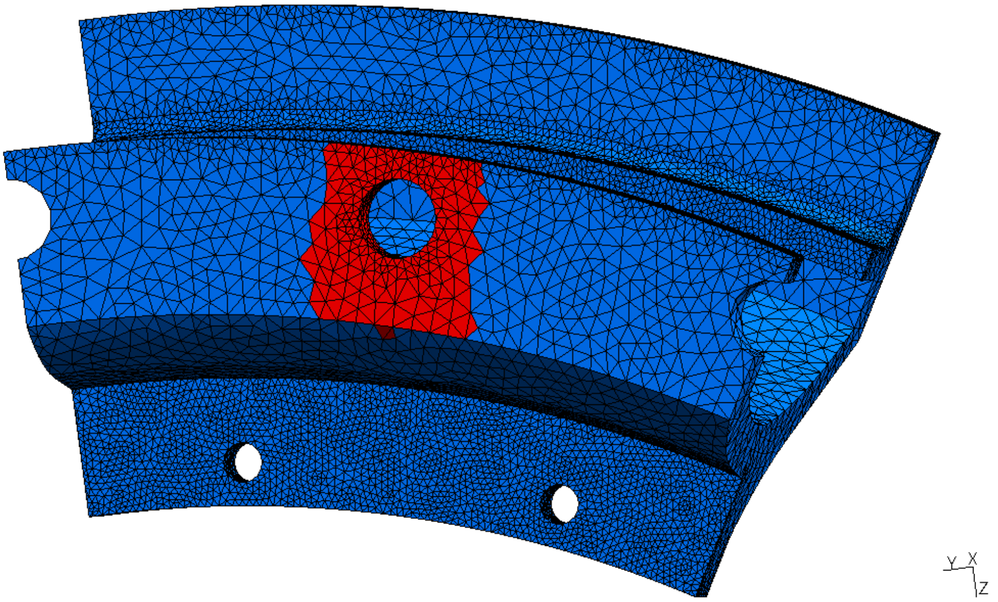


Figure 1: Decomposition of a model into two regions for the use of the plug-in Morfeo/crack for Samcef. The XFE region is in red while the FE region is in blue

Even if the XFEM allows for propagating a crack without the need of mesh conformed to the crack faces, a sufficiently fine mesh is required in order to capture the three-dimensional stress field along the crack tip. Two strategies can be applied: the mesh is refined at the first propagation step and remains unchanged until the propagation ends or the mesh is refined according to the crack geometry at each propagation step. In the current official version of the plug-in Morfeo/Crack for Samcef, only the first strategy is available; the second one has been succesfully used at Cenaero for recent industrial projects. The crack is introduced inside the model by giving either a geometrical description or a triangulated surface. Figure 2 shows an example of a refined XFE region with an edge crack.

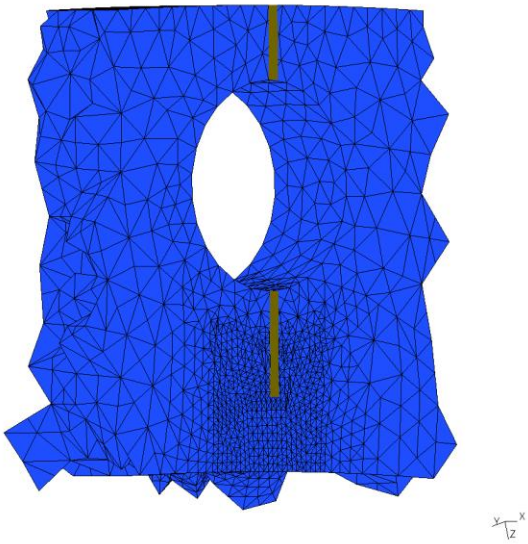


Figure 2: Edge crack inserted in a refined mesh

The coupled FEM/XFEM problem is then solved with the help of appropriate solvers (FETI or Mumps). The stress intensity factors and the crack propagation are post-processed by Morfeo. Various crack propagation laws are available, among them there are the Paris, Elber, Forman and Nasgro laws

Methodology assessment

Several validation cases have been realized and published in international journals and conferences by Cenaero. Some of them are commented in this paper.

Inclined crack in a 3D bar

A 3D bar containing a center crack is subjected to a uniform traction. The crack is oriented with a variable angle from 0° to 90° as illustrated at the figure 3. The model paremeters are described in the table 1. The mean values of the stress intensity factors are compared to the analytical solution and a crack box solution obtained with Samcef. The FEM and XFEM solutions shown at the figure 4 are in a perfect agreement while a difference of 4% is observed when comparing to the analytical solution. This difference is due to the 3D effects [WYA07, WYA08]. It has been demonstrated that considering Poisson's coefficient equal to zero, the analytical solution and both FEM and XFEM solutions are identical [WYA07].

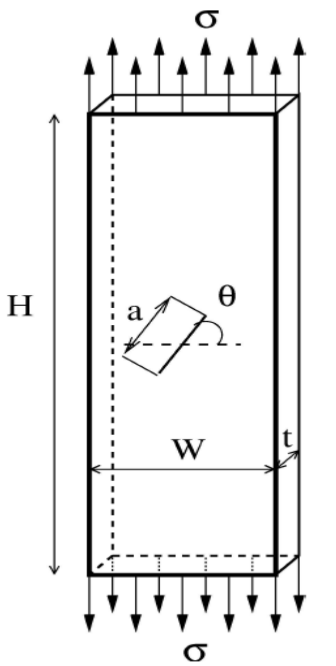
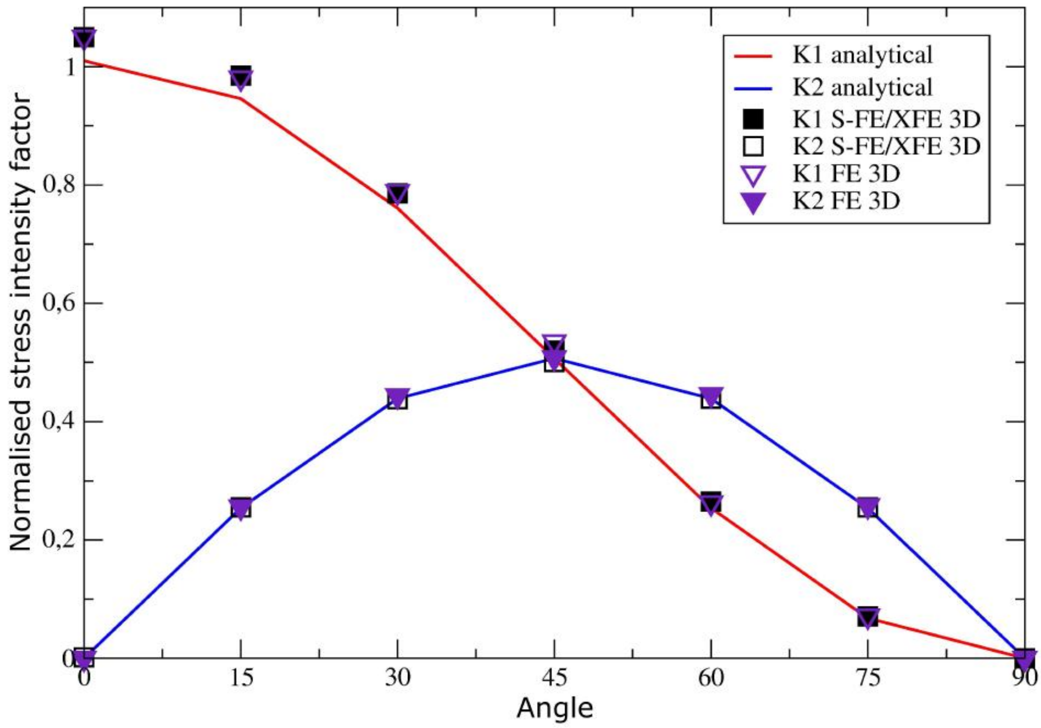


Figure 3: Inclined center crack in a 3D bar

H	500 mm
W	100 mm
t	2.5 mm
a	20 mm
θ	from 0^o to 90^o by step of 15^o
E	210 GPa
ν	0.3
σ	1

Table 1: Geometrical properties



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igure 4: Stress intensity factors for an inclined center crack

Semi-circular crack in a plate under bending

A plate containing a semi-circular crack is subjected to bending. The description of the geometry is provided in figure 5 and in table 2. The reference solution has been provide by Newman and Raju. The comparison is given in figure 6.

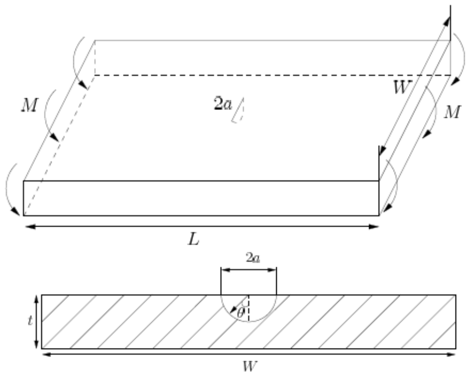

Figure 5: Semi-circular crack in a plate subject to bending

W	20 mm
L	20 mm
t	1 mm
a	0.5 mm
E	210 GPa
ν	0.3

Table 2: Plate and crack parameters

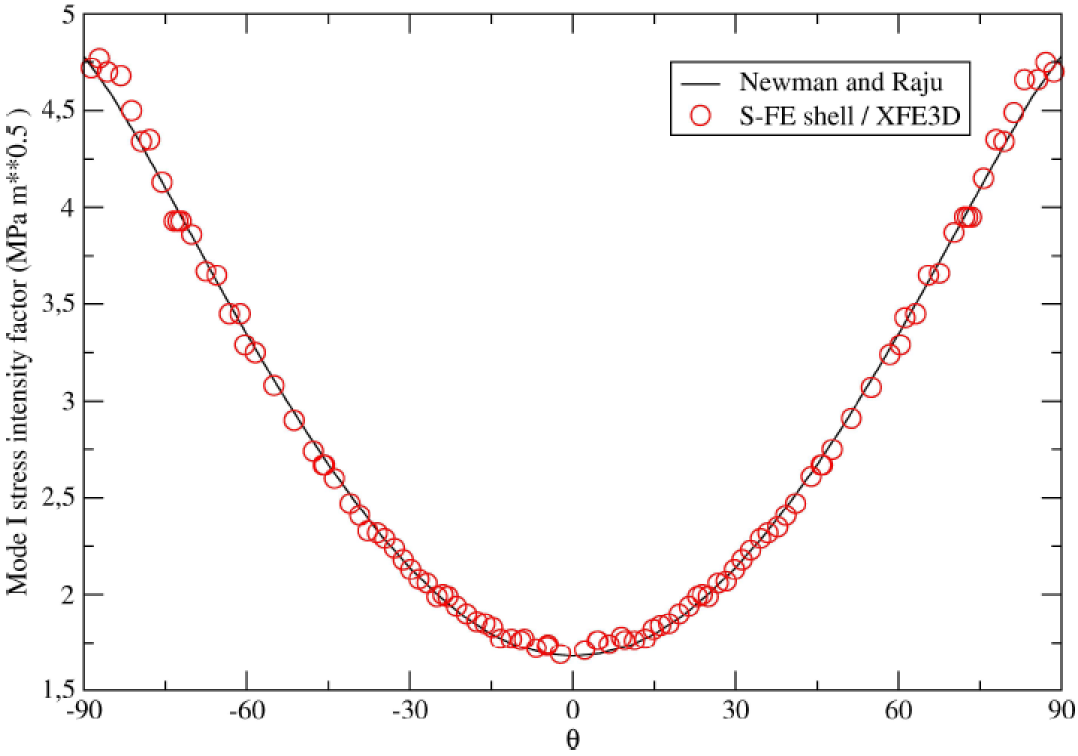

Figure 6: Comparison between the Plug-in Morfeo/Crack for Samcef solutions and the Newman and Raju solution for a plate in bending with a semi-circular crack

Connecting lug

A crack is inserted in a connecting lug. The initiation point is located in the contact area. The description of the specimen is provided in figure 7 and table 3. The solution is compared with Samcef using crack box[WYA09].

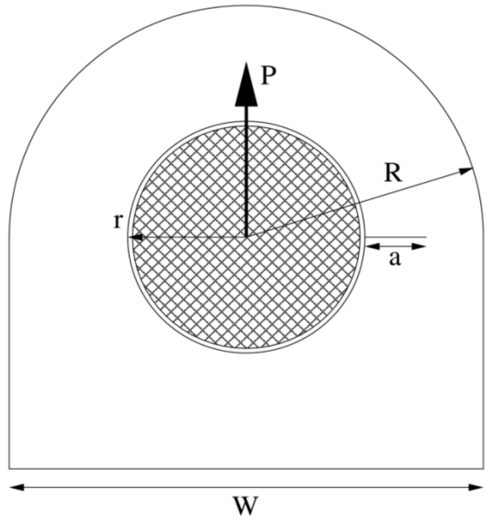

Figure 7: Connecting lug with an edge crack in the contact area

W	20
R	10
r	5
t	5
a	2.5
E	210GPa
v	0.3
P	6kN

Table 3: Description of the connecting lug

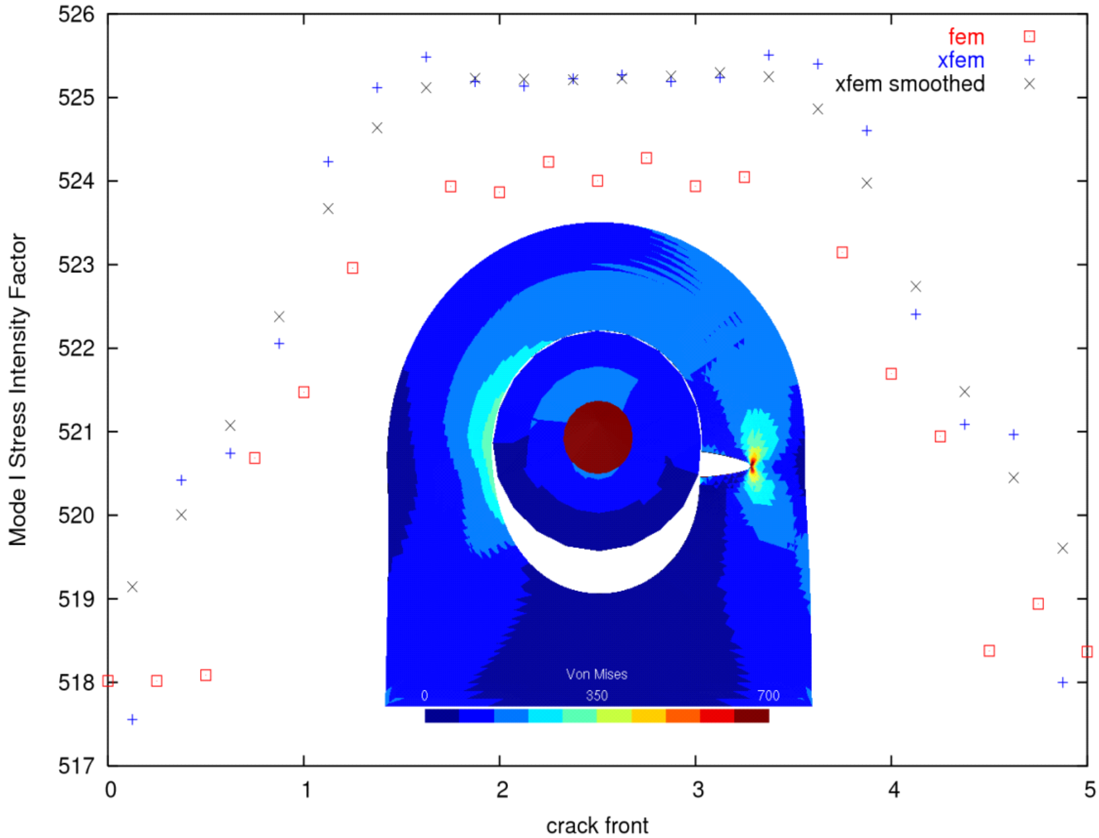

Figure 8: Stress intensity factor for a connecting lug with an edge crack

Figure 8 shows a good agreement between the FEM and the XFEM solution obtained with the plug-in Morfeo/Crack for Samcef used with MECANO. The difference between both solutions is below 0.5%.

Stator blade under complex loading

This application concerns a generic stator blade subject to a complex loading. The geometry is shown in figure 9. The loading consists in a thermal gradient, a constant pressure and vibration loads. The vibration loads are extracted from a Dynam computation.

Figure 9: Stator blade geometry

The thermal load distribution is shown in figure 10. A constant pressure is applied on the suction face and the vibration loads come from the first vibration mode of the blade.

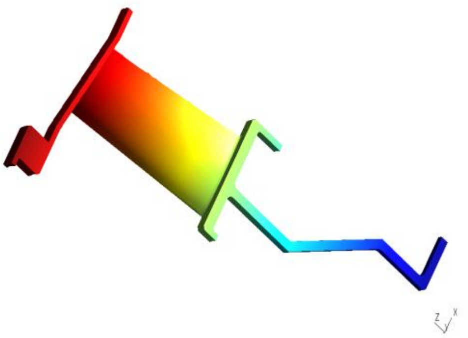

Figure 10: Thermal distribution on the stator blade

The quarter-circular crack is inserted at the trailing edge of the blade based on the principal stress tensor. In this application, adaptive mesh refinement is used in order to follow the location of the crack tip. The mesh is adapted at each crack propagation step. Figure 11 shows the initial crack location on the initial unrefined mesh and the associated refined mesh.

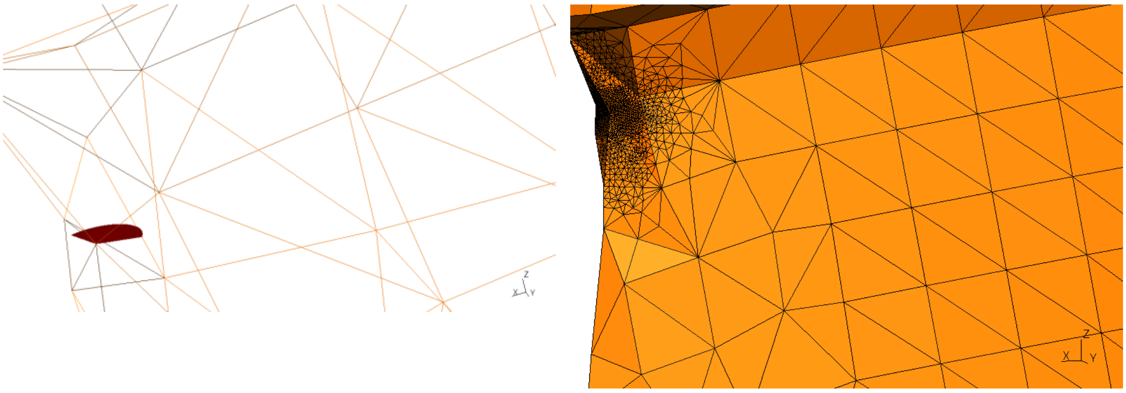

Figure 11: Initial crack on the unrefined mesh and the associated refined mesh

The crack grows according to a Paris law and the crack growth angle is governed by the average stress intensity factors. Figure 12 shows the final computed crack shape. The propagation stops after a certain number of cycles.

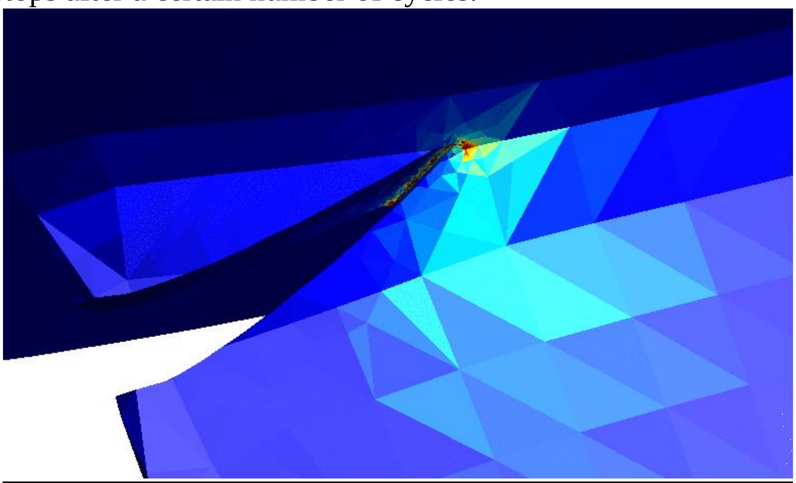

Figure 12: Final crack shape for a stator blade subjected to a complex loading

Concluding remarks

The plug-in Morfeo/crack for Samcef is a dedicated tools for fatigue crack growth analysis in complex three-dimensional components. It is based on a substructuring approach where the model is decomposed into two regions, one for the uncracked part handled by Samcef and another one for the cracked part handled by Morfeo. Some validation cases are provided which assess the method and its implementation in Morfeo and plug-in solutions. A demonstration of a fatigue crack growth under vibration loads is presented on a stator blade subjected to a complex loading conditions.

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