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Application of SFEM Method to Analyse Crack Parameters of Ultra High Molecular Weight Polyethylene Material

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Abstract: The application of numerical methods, today occupies a much needed place for modeling, and for finding solutions to any problem related to fatigue and damage to materials. This article deals numerically with the evolution of the stress intensity factor and the integral of the contour J in I mode, of an initial rectilinear crack of languor a=0.7, 1.4, 2.1, 2.8 and 3.5mm, with different ratio, a/w=0.1, 0.2, 0.3, 0.4 and 0.5mm. By the stretching finite element method (SFEM) of the (UHMWPE) Ultra High Molecular Weight Polyethylene material. On the other hand, the creation of the parametric mesh based on the computer language (FORTRAN) and to create a model of the square crack front with 5 contours of size L=1mm. In addition, the simulation was done by Abaqus 16.3.1 code. The maximal circumferential stress criterion MCSC were applied. Other materials like Alu20-17 and Steel XC65-90 were used to make the comparison. Crack parameters, such as stress intensity factors KI, KII and J-contour integral were evaluated. The results obtained in our work have justified that there is proportionality between the three materials.

Keywords: Crack, FIC, SFEM, UHMWPE.

1. INTRODUCTION

Today, several materials used in the field of fracture mechanics, among these materials used for a long time in fracture mechanics, Ultra High Molecular Weight Polyethylene (UHMWPE) is a thermoplastic material which is very important as support material in total knee and hip replacement. Its component due to its excellent mechanical properties, such as

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outstanding impact resistance, high strength, low creep, low coefficient of frictional abrasion resistance and the biocompatibility has been used in medical applications as a hip joint. Recent work suggests, Charnley (1972) [1] discovered that ultra-high molecular weight polyethylene (UHMWPE) has been the primary material of choice for total joint arthroplasty (TJR) prosthesis over the past three decades. Murakami et al (1987) [2] Troha et al (1988) [3] observed that crack closure is very important in some polymers and fiber reinforced plastics.
Taylor (1989) [4] proposed another factor that might be likely to modify the fatigue crack propagation behavior of UHMWPE, is crack closure and refers to premature contact between the faces of the crack during cyclic loading.
Closing the crack reduces the cyclic stress intensity at the crack tip; if fatigue crack propagation behavior is not taken into account, the threshold regime may be overestimated. Bartel et al (1995) [5] believe that cracks propagate due to cyclic tensile and compressive stresses acting on and under the running surface.
Baker et al 1998 [6] have improved certain mechanical properties, such as creep resistance and resistance to fatigue crack propagation.
Furmanski et al 2009 [7], Furmanski et al 2010 [8] found the toughness and resistance reducing crack propagation, of cross-linked formulations of UHMWPE are of interest for clinical applications, especially in light of cases recently reported damage or catastrophic brittle fracture of heavily cross-linked THA bearings.
Eddoumy 2012 [9] defined ultra-high molecular weight polyethylene (UHMWPE) as a material used as a bearing component in joint prostheses, the durability of which depends on the chemical and mechanical properties of this polymer.
Furmansky et al., 2009 [7] Tawer et al. 2007 [10] said that the durability and resistance to crack propagation of UHMWPE played an important role, in total joint joints, due to oxidation problems in conventional installations and extending to concerns of reduced material strength and hardness evident in abrasion-resistant crosslinked UHMWPE installations.
Medel et al 2009[11] reported that fatigue crack propagation has been useful for comparing the relative fatigue performance of UHMWPE material, but their usefulness as an intrinsic property of the material has been questioned. On the other hand, Bentahar et al [12], Bentahar and Benzaama [13] used a new method (SFEM) to characterize the stress intensity factors in the initial crack of the crack tip.

Fracture Mechanics

A. Crack Propagation Law (Paris Law)

The crack propagation law was proposed by Paris and Erdogan (1963) [14], this law is used to model the fatigue crack propagation in the 2D case.

$$\frac{d_a}{d_N} = C(\Delta K)^m \quad \text{where} \tag{1}$$

C and m are the material properties, (a) is the crack length, (N) is the number of loading cycles and ΔK is the change in stress intensity factor.

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B. Stress Intensity Factor

Saverio [15] has defined that the stress intensity factor K is a parameter which makes it possible to know the state of stress and strain at any point in the vicinity of the crack.

$$\mathrm{KI} = \mathrm{Y}\sigma\sqrt{a\pi} \tag{2}$$

where, F is the geometric correction factor of the model used.

$$Y = 1.12 - 0.23\left(\frac{a}{C}\right) + 10.6\left(\frac{a}{C}\right)^2 - 21.7\left(\frac{a}{C}\right)^3 + 30.4\left(\frac{a}{C}\right)^4 \tag{3}$$

Where the stress intensity factor KII is given by the relation.

$$KI\,\sin\theta + KII\,(3\cos\theta - 1) = 0 \tag{4}$$

C. Maximum Circumferential Stress Criterion (MCSC)

According to this criterion, the crack propagates in the direction for which the hoop stress is maximum. This is a local approach since the direction of crack growth is directly determined by the local stress field along a small

$$\tan\left(\frac{\theta}{2}\right) = \frac{1}{4}\left(\frac{KI}{KII}\right) \pm \frac{1}{4}\sqrt{\left(\frac{KI}{KII}\right)^2 + 8} \tag{5}$$

Circle of radius (r) centered at the bottom of the crack. The bending angle of the propagating crack can be determined after calculating the values of the stress intensity factors KI and KII.

where KI and KII are the stress intensity factors corresponding to mode I and mode II loading, respectively

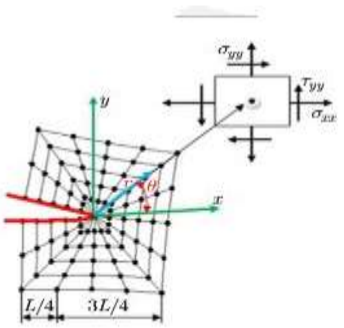

Fig. 1 Stress field in the vicinity of the crack front

Tada et al. (2000) [16] gave the general equation of the 2D stress field near the crack tip defined by the stress intensity factor K.

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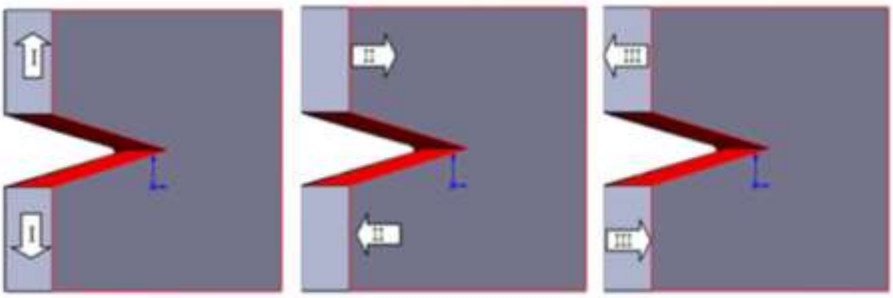
$$\sigma_{i,j}^{I,II}(r,\theta)=\frac{KI,II}{\sqrt{2\pi r}}f_{ij}(\theta) \quad (6)$$

KI,II is the SIF in mode I and II,
$\sigma_{i,j}^{I,II}$ is the stress field associated with mode I.

$$\sigma_{xx}=\frac{KI}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\left(1-\sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right),$$
$$\sigma_{yy}=\frac{KI}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\left(1+\sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right),\quad \tau_{xy}=\frac{KI}{\sqrt{2\pi r}}\sin\frac{\theta}{2}\cos\frac{\theta}{2}\cos\frac{3\theta}{2} \quad (7)$$



(a) (b) (c)

Fig. 2 Illustration of failure cracking modes: a) Mode I is the opening mode, b) Mode II is the shear mode in the crack plane and c) Mode III is the tear mode [17].

Mechanical Properties of Materials

The mechanical characteristics of the materials are presented in Table 1.

Material	E(MPa)	ν
UHMWPE	10^9	0.46
Alu20-17	75000	0.3
Acier XC65-90	230000	0.3

Numerical Model

The structure is a plate contains an initial crack, as shown in Fig. 3. Under a uniform tensile load is see Fig. 3. The geometric dimensions of this plate is 16 mm x 7 mm (C x W), crack length ratio a/w = 0.1, 0.2, 0.3, 0.4 and 0.5. The three materials are UHMWPE, Alu20-17 and XC65-90 steel, the characteristics of the materials are shown in Table 1. The structure subjected to uniform tensile load σ=100 MPa. The length of the crack front L = 1mm. The parametric mesh consists of 478 square elements of the CPE4 type with four nodes applied in all materials.

By applying the SFEM method, the stress intensity factors (KI.KII) and the contour integral (J) are determined for the different values of the ratio of a/w = 0.1, 0.2, 0, 3, 0.4 and 0.5 and compared with each other.

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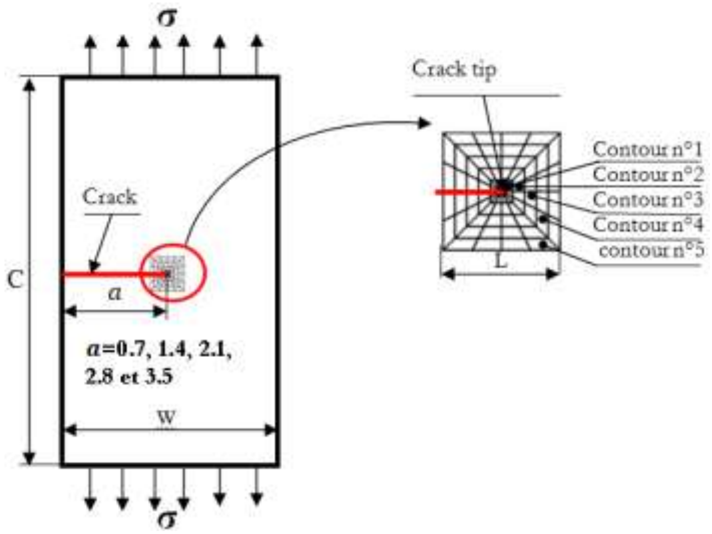

Fig. 3 plate model with boundary conditions

2. RESULTATS AND MODELISATION

The figures below present the model, by the SFEM method in mode I with different initial crack lengths, in the cases of (a) =0.7mm, 1.4, 2.1, 2.8 and 3.5mm.

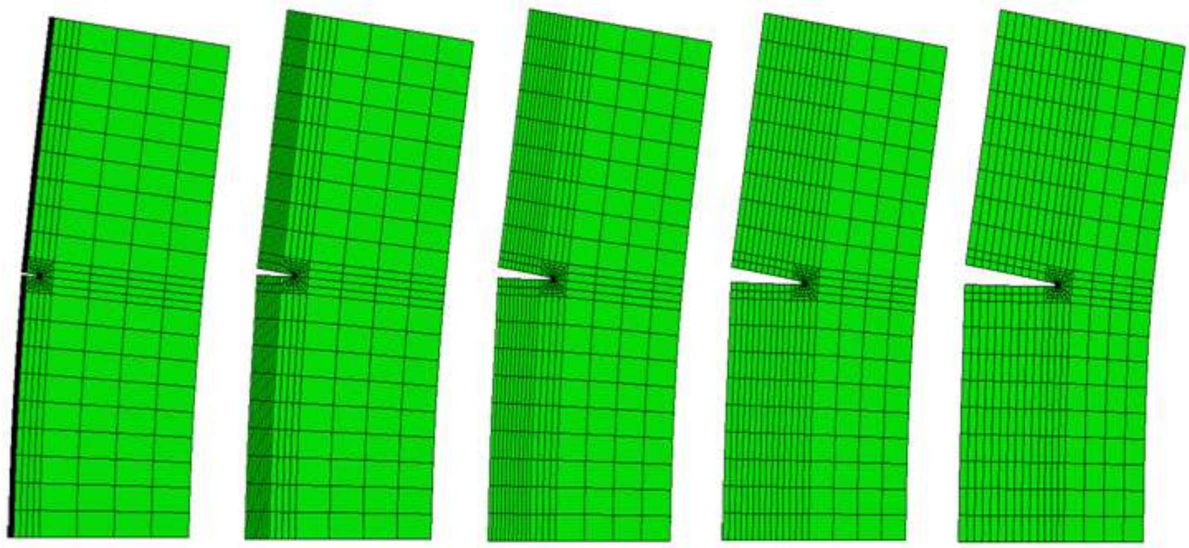

Fig. 4 SFEM model for different crack lengths a=0.7, 1.4, 2.1, 2.8, and 3.5mm

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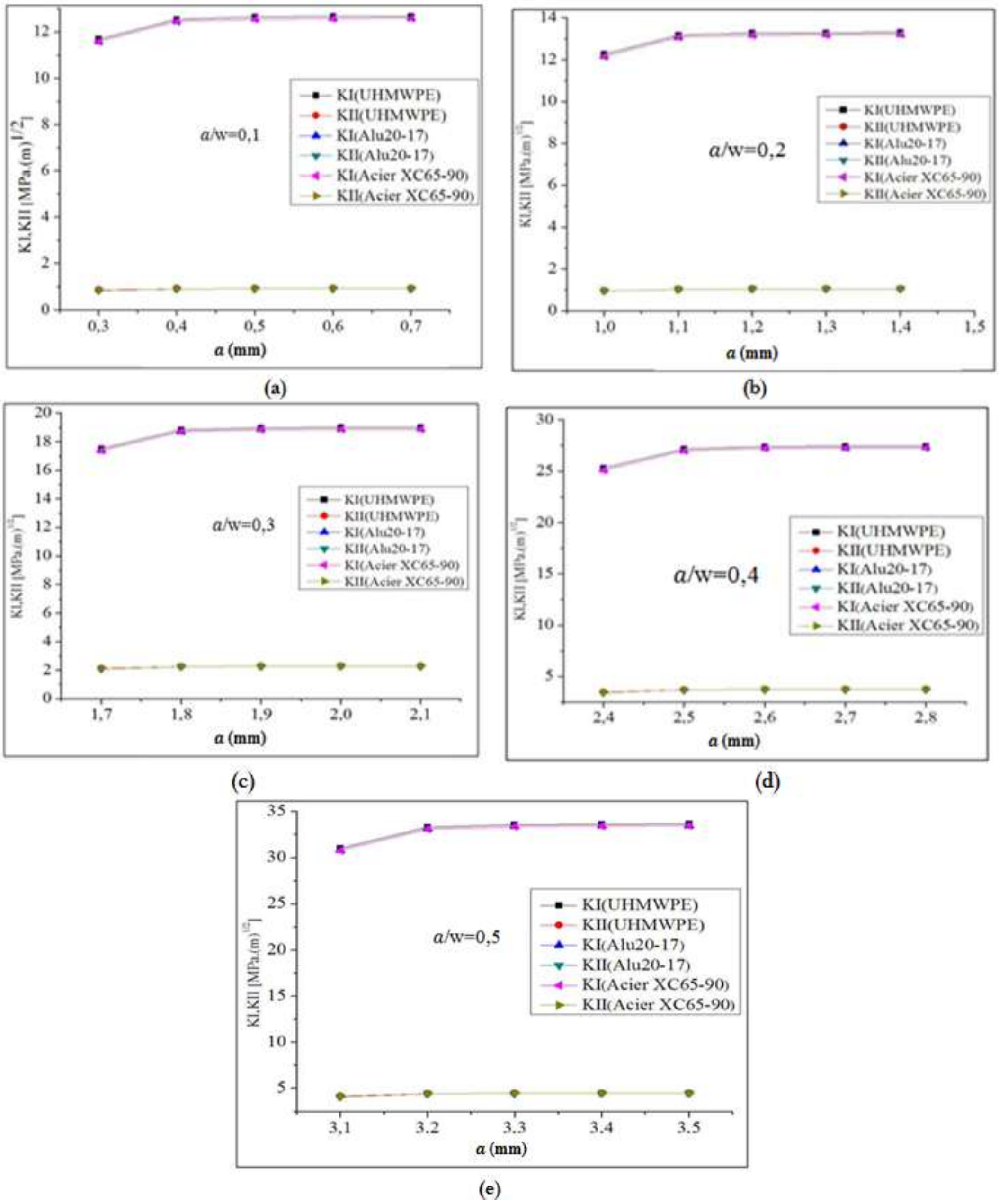

Fig. 5 Evolution of the FIC in mode I between the three materials (UHMW-PE, Alu20-17 and Steel XC65-90) in the different cases: a) a/w=0.1, b) a/w=0.2, c) a/w=0.3, d) a/w=0.4 and e) a/w=0.5.

Figure 5 shows the evolution of the stress intensity factor as a function of the crack length, concerning the various materials studied, this evolution makes it possible to give the difference between the three materials at the bottom of the crack of each material.
The more the ratio (a/w) increases, the more the stress intensity factors (KI and KII) increase. From fig 5, it is observed that the values of KI and KII remain stable in all cases of the ratio (a/w) of 0.1 to 0.5mm under the uniform tensile loading.

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It can be noticed that the comparison between them are very proportional to (KI and KII). Increasing the crack length provokes causes an increase in the stress intensity factors (KI and KII).

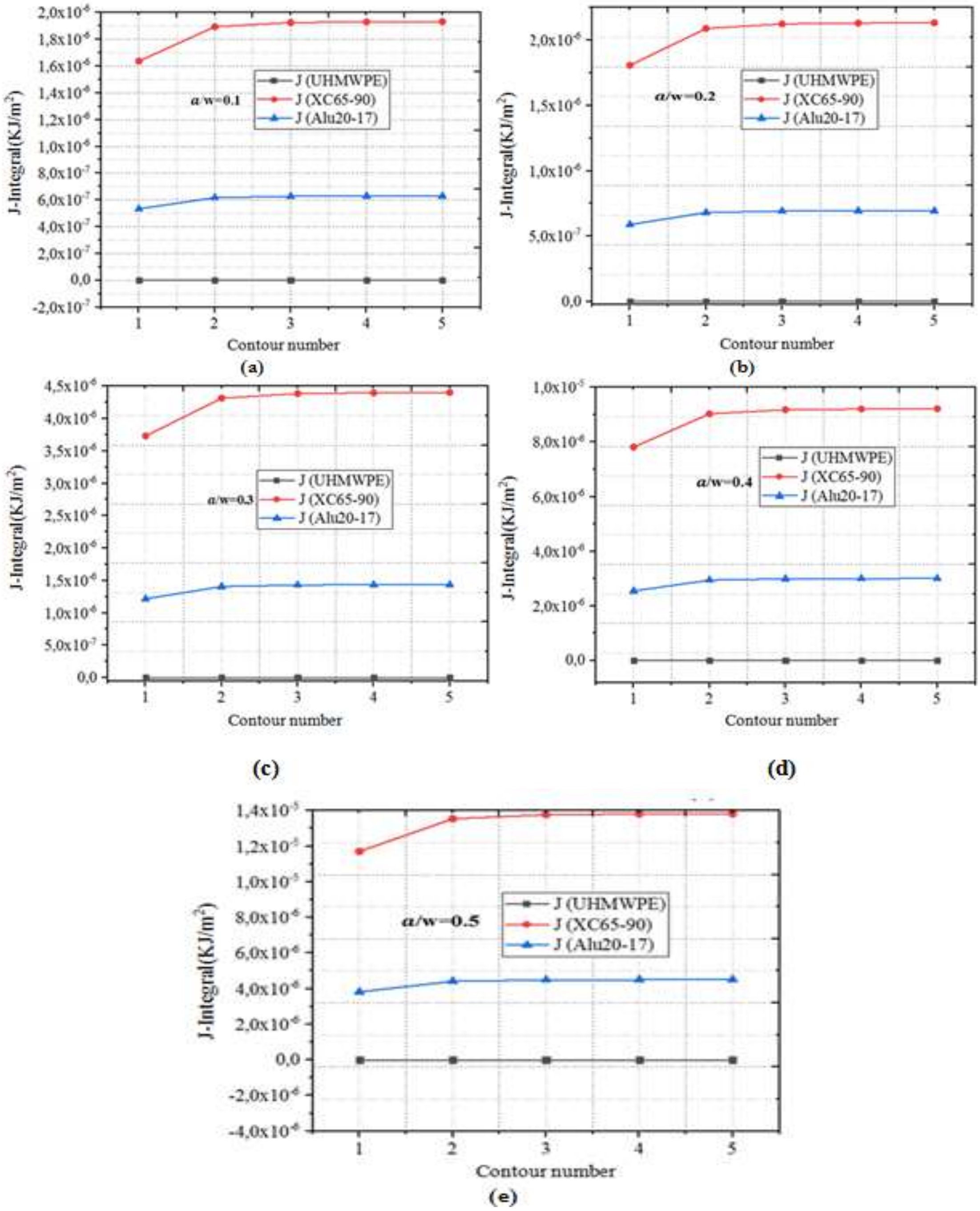

Fig. 6 Evolution du contour J en mode I entre les trois matériaux (UHMW-PE, Alu20-17 et Acier XC65-90) concernant les différents cas du rapport a/w : a) a/w=0.1, b) a / w=0.2, c) a/w=0.3, d) a/w=0.4 et e) a/w=0.5

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From figure 6, we observe that the evolution of the contour J in mode I between the three materials (UHMW-PE, Alu20-17 and Steel XC65-90) in the different cases of the a/w ratio, is increased by 0.1 to 0.5 under uniform tensile load.
The values of the integral of the contour J is close to zero under tensile load, for the material UHMW-PE, Thus, the SFEM method presents higher values concerning the materials with low Poisson's ratio value. it is concluded that the maximum value of J obtained by method SFEM is in the material of steel XC65-90. On the other hand, we note that the increase in the ratio a/w causes an increase in the integral J. Indeed, from this figure we can notice that the values of J become constant from the second contour K These results are proven by d'Aboulghit [18] and by the ABAQUS documentation which suggests taking the average of the calculations from the different contours without taking into account the value of the first contour.

3. CONCLUSION

In the present work, the stress intensity factors and the integral of the contour (J) in mode I, of an edge cracked plate with different ratio of a/w were evaluated using the SFEM method. , under uniform tensile loading for the three materials UHMW-PE, Alu20-17 and XC65-90 steel.
The following observations were found during this numerical simulation study:
- With increasing crack length, the SIF KI and KII increase.
- As the contour number increases, the contour integral J increases, while the remaining results of the contour integral J remain constant.
- By method SFEM the model is keeps the same number of node and elements in all the cases of crack length of a=0.7, 1.4, 2.1, 2.8 and 3.5mm.

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