Two-dimensional Analysis of the Evolution of the Stress Intensity Factor in the Cement of the Acétabulum THR

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Résumé : La rupture du ciment orthopédique est pratiquement la cause essentielle de ce descellement. Le comportement d'une fissure initiée dans le ciment chirurgical (polyméthylemétacrylate 'PMMA') est d'une grande nécessité pour la compréhension des phénomènes de descellement des prothèses totales de hanche. Dans ce travail nous analysons numériquement bi-dimensionnellement par la méthode des éléments finit l'interaction des fissures émanant d'un défaut, afin de savoir l'effet de l'interaction sur l'évolution de facteur d'intensité de contraintes dans les trois zones du fémur de la prothèse de hanche. Cette répartition a été faite dans les trois zones (distale, médiale et proximale) de ses composantes. Avec une charge répartie sur la tête fémorale de fémur d'un poids moyen de 90 kg d'un être humain. La direction de fissure est dans l'axe du chargement. Les résultats obtenus prouvent que le ciment Orthopédique est soumis à des efforts de compression sous l'effet de charge.
Mots-clefs*: fémur, micro-fissure, Ciment, facteur d'intensité de contrainte, méthode des éléments finis*

Abstract: *Breaking cement is practically the main cause of this loosening. The behaviour of a crack initiated in the bone cement (polyméthylemétacrylate PMMA) is a great need for understanding the phenomena of loosening of total hip prostheses. In this study we analysed bi-dimensionally numerically by the finite element method of interacting cracks from a defect, in order to know the effect of the interaction on the evolution of the stress intensity factor in the three zones of femur hip. This distribution was made in the three areas (distal, medial and proximal) of its components. With a distributed over the femoral head of a femur with an average weight of 90 kg for a human being supported. The direction of crack is in the axis of loading [1]. The results obtained show that the bone cement is subjected to compressive forces under the effect of load.*
Keywords - *crack, Cement, Stress intensity factor, Finite element method, Acétabulum*

1. Introduction

The acrylic cement (PMMA) is used in orthopedic surgery is considered the weakest link in the chain charge transfer implant -cement -cup, so this material is primarily responsible for the life of the total prosthesis the hip. Several studies on the analysis of the stress distribution in the orthopedic cement were conducted. Thus Benbarek et al [1] have analyzed numerically by the finite element method, the effect of the orientation of the axis of the implant relative to that of the cup on the level and the distribution of stresses in the bone cement containing a microcavity and therefore the stress intensity factor at the crack tip heads from said cavity. In another study, Bachir Bouiadjra et al [2] have studied the behavior of cement out of the acetabulum by analyzing the intensity factor. They show that the failure mode depends on the position of the crack.

The analysis of the stress distribution in the bone cement of a Total Hip Prosthesis, taking into account the micro- defects (voids, cracks, ...) and their interactions present in the cement has been the subject of numerous studies researchers in this field [4], [5], [6]. Benbarek et al [7] [8] have used numerical analysis in the orthopedic cement in the acetabular part, they examined the variation of the stress intensity factor of crack from a cavity the XFEM based on position , loading and orientation ; that to predict angle and optimum loading for crack propagation; ouinas et al [9] conducted a numerical study on the femoral part based on the effect of dynamic loading, the propagation of the long cement cracks, to describe the fracture behavior of PTH; Other studies [10] showed that the presence of a cavity in the cement increases the damage parameters. When the cavity is situated in the cement according to the loading axis. If the cavity changes its shape to an elliptical shape, the size of the damaged area increases, thus providing a crack in cement. Bouziane et al [11] showed that the stress intensity factor for a crack from an is higher than the crack from a bone cavity inclusion. A. Ramos et al [12], have observed experimentally that the positioning of the implant within the femur and adjusting the femoral canal are two important points in the mechanism of the formation of cracks in both interfaces (Os- cement, Cement-Imaplnt). Sandro et al [13], analyzed by finite distribution of stresses in the acetabular part by PTH screw fixation element, the analysis shows that the constraints are quite amount to provide tractor it to the bone interface metal; Taylor et al, [14] used analytical and numerical methods to predict damage to the bone; Nabais et al [15] were based on the finite element method by applying the evaluation study damage the bone-cement interface in a model of cemented hip prosthesis simple. Renato et al [16] cited the causes of failure of metallic materials used in biomechanics by cyclic constraints; they have sought to correlate the structural aspects and the surface of these materials and the onset of fatigue in the environment of the human body.

2. Geometric model and limits condition

The acétabulum cavity is located on the outer face of the pelvic bone at the junction of its three component parts in Figure 1, Figure 2 illustrates the geometric model of the acétabulum and its mesh. This modeling was done using the software of finite element: Abaqus 9-11 [17]. The geometry in Figure 1 treated;

The boundary conditions used in this case are:

- A flush imposed on the pubis;
- A zero imposed displacement along the axis "x=0" (not allowed in the direction of displacement x) on the wing of the pubis;
- A uniformly distributed load of 5MPa amplitude applied to the implant [13].

In Table 1 are combined mechanical properties of the constituents of the Hip whose resilient behavior is assumed.

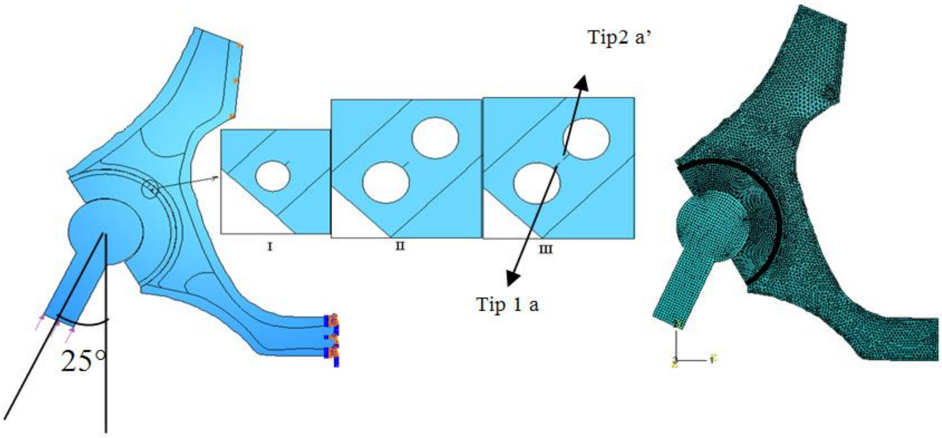


Figure 1. Schematic representation of the boundary conditions and the mesh adopted.

Table 1. Mechanical properties of TPH constituent materials [2].

	Young's Modulus E (MPa)	Poisson's ratio (ν)	Tensile break strength (MPa)	Tensile Compression (MPa)
Cortical bone	17000	0.30	100	200
Spongious bone **1–2 – 3**	132 – 70 – 2	0.20		
Sub-chondral bone	2 000	0.30		
Cup (UHMWPE)	690	0.35	40	20
Cement (PMMA)	2 300	0,30	25	80
Metallic implant	210 000	0.30		

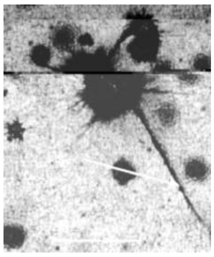


Figure 2. Interaction of defects and cracks in acrylic bone cement observed under transmitted light [6].

3. Results

1.3. Behavior cement under presence of cavities

The results of this analysis are illustrated in figures 4. (a and b). These show the variation of the equivalent stress near the cavity with a size of 200µm (0.2 mm) figures.3, is circular and is assumed games diameter ratio d_1/d_2, that induced in the cement according to the angle of its shape. They clearly show that the stress distribution around the defect is not homogeneous and that whatever its position in the cement. The variation of these stresses along the scan line is almost periodic. The stress tends to take values out of its tensile stress. This behavior is observed when the fault is oriented at 0°, 180° respectively relative to the reference axis to position '0 ' at the interface Cup Cement, and '1' with the cement-bone interface . Such forms and fault may initiate a propagating crack in cement leads to loosening of the structure. The presence of a defect in the polymer material in the close vicinity of a foreign body may increase this phenomenon.

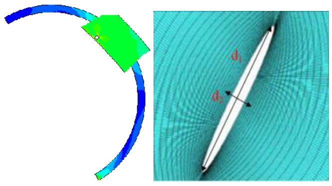
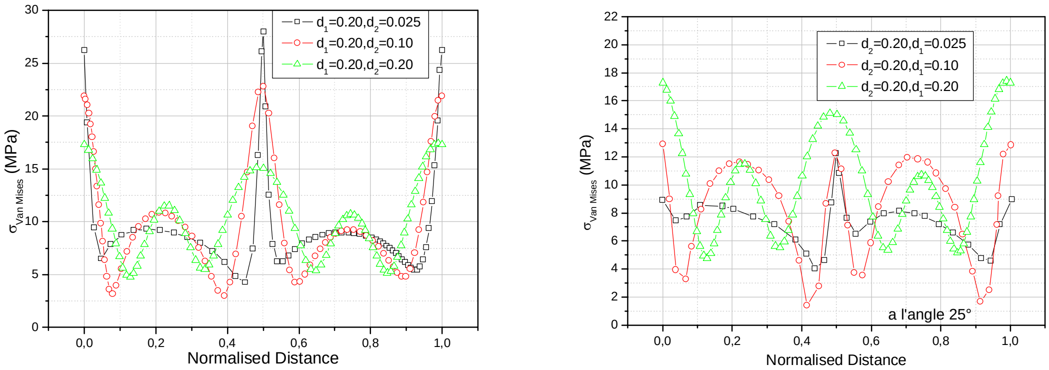


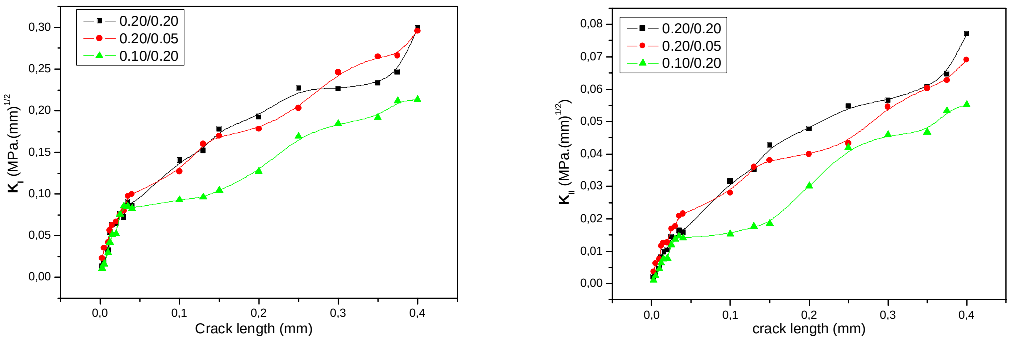
Figure 3. The presence of the cement with the cavity and around the mesh elliptical defect analyzed according to its diameter ratio d_1/d_2.



(a) (b)

Figure 4.Repairing similar constraints default circular contour and ellipsoidal 25° (a, b).

2.3. Case of a crack emanating from a cavity (case I)



(a) (b)

Figure 5. Variation FIC mode I and II crack tip from a cavity as a function of the size of the crack and defect diameter ratio (a), (b).

In the figures (5.a and b) represents the stress intensity factor depends on the position of the cement cracked (one crack imamate cavity (case I). Indeed, the maximum values for this factor are achieved in the circular area of defect. In this report, the stress intensity factor is significant then decreases or failure has flattened that is to say, the inverse ratio of diameter. A tendency of the crack size less than 0.1mm leads at low values of the stress intensity factor. When the crack size increases more 0.1mm of the stress intensity factor increases in absolute value. Such a crack, characterized by a stress intensity factor always winded, is energetically unstable. Under the effect of mechanical change this crack therefore tends to have opened. Means that the cement has the risk of damage to the prosthesis compared. Positive values of the stress intensity factor clearly show that cement is unlike compression. The difference between the stress intensity factors both reports is too pronounced. This same behavior is also observed in mode II (Fig. 5b). This figure shows the variation of the stress intensity factor in the mode II initiated crack tip of a cavity in the cement for different ratios of the latter.

3.3. The interaction of a crack from a cavity - circular cavity (case II)

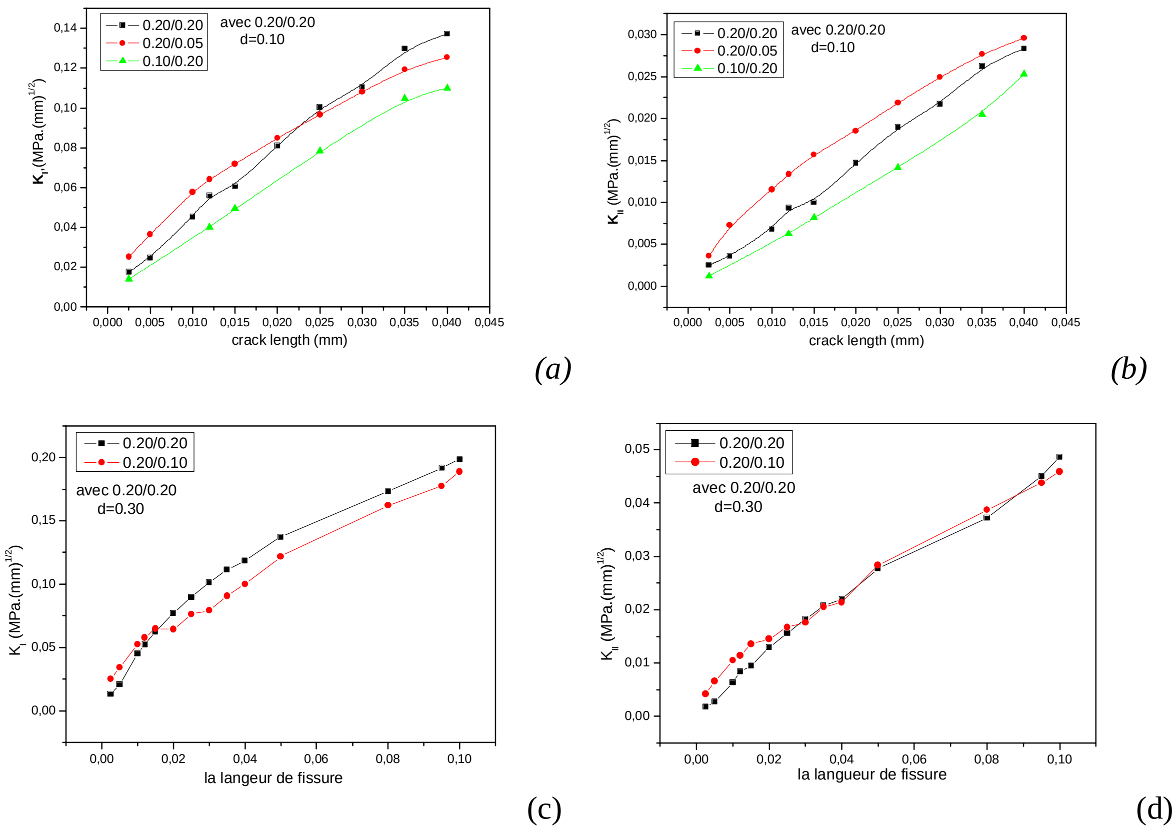


Figure 6. Variation of the FIC in mode I and II for d_1/d_2 reports come with a crack, with a distance d=0.10, 0.30mm and circular defect 0.20/0.20 (a, b, c and d).

Figure 6. (a, b, c and d), illustrates the variation of the stress intensity factor in modes I and II according to the size of a crack from the cavity and the inter - distance between default circular aligned on the same axis of the bone cement loading of the prosthesis of the implant. Thus, regardless of the area of crack initiation, this factor is positive. Indeed, it depends on the intensity of the stress field in which the crack is located. To a decrease in the inter- distance stress intensity factor augment a remarkable way, beyond a certain default size FIC comes to increasing and that whatever the default size, heads crack lead to the same value of stress intensity factor for different area. Our results show that the interaction of the cavity is the heads of the crack does not lead to the same stress intensity factor, the difference is too pronounced factors for positions of the crack between the distance d=0.1cm . Our results say that the size of the crack and the inter-distance increases the risk of crack growth. This risk is higher for weak interaction.

4.3. The interaction between two cracks emanating from a cavity - circular cavity (case III)

The following figures 7 and 8 (a, b, c and d) respectively show the variation of the stress intensity factor in CIF mode I and II crack tip 1 and 2 in the cement for different size and inter-distance between them , we note that the stress intensity factor increases with the decrease of the interaction distance for various defect report. In fact, the highest values of this factor in the cement Revenue Is peak at the vicinity of the crack-cement interface Cup. Believe these values by increasing the crack size and the inter-distance.

The cement a short distance interaction and a large size of the crack presents the risk of damage to the prosthesis, thus the risk of breakage caused cements since not have good resistance to tensile forces.

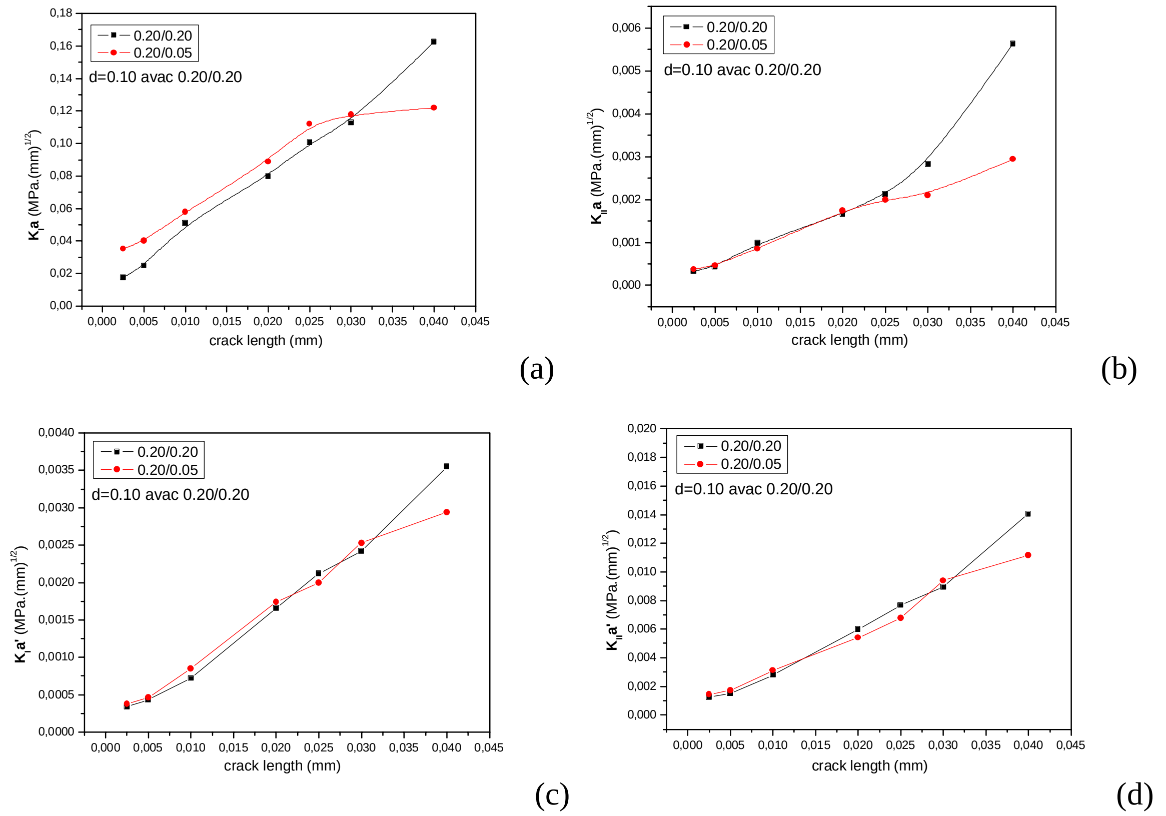
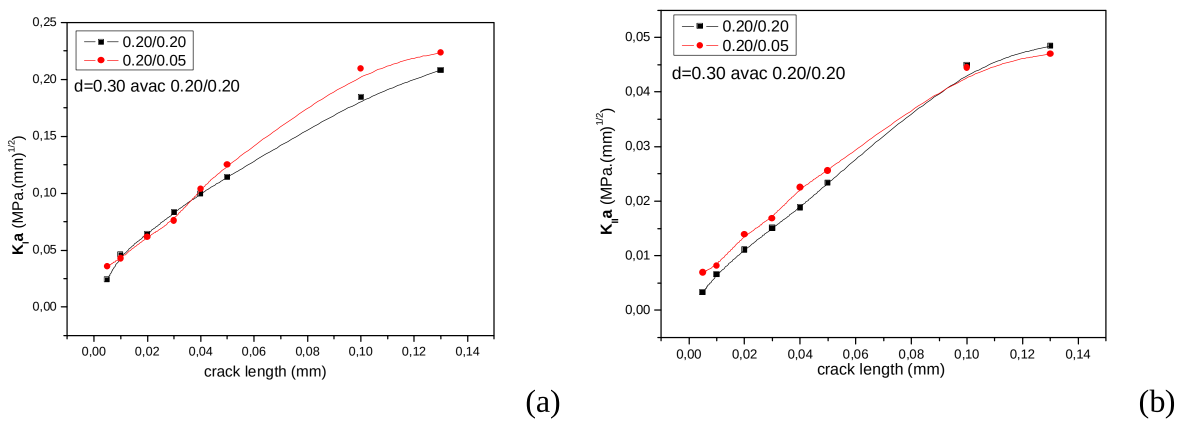
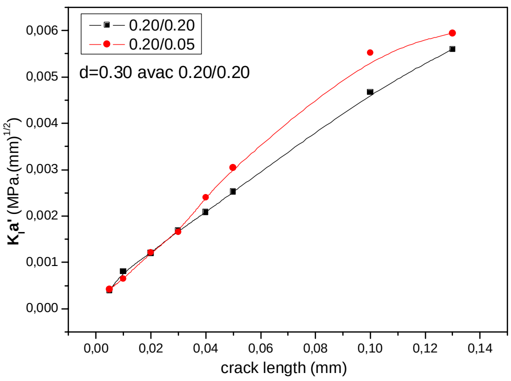
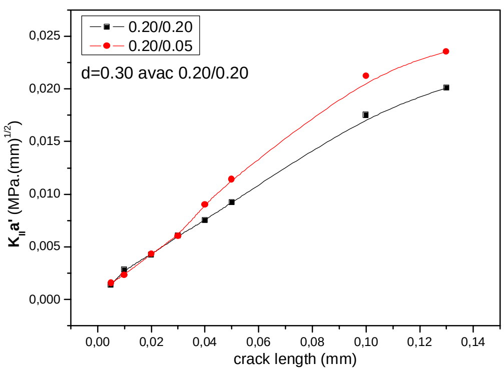


Figure 7. Variation of the FIC mode I and II crack tip1 and 2 from a cavity as a function of the separation distance d=0.10mm and a cavity position (Case II) (a, b, c and d).





(c)



(d)

Figure 8. Variation of the FIC mode I and II crack tip1 and 2 from a cavity as a function of the separation distance d=0.30mm and a cavity position (Case II) (a, b, c and d).

4. Conclusion

The results obtained in this study show that:

- The most important FICs induced in the cement where the adjacent cavity closer, and the diameter ratio seems circular;

- The presence of cracks in the cement at the interface of the cup with mechanical viewpoint is detrimental since they can cause the loosening of the prosthesis;

We analyzed in this study the influence of a crack from a cavity near the interface on the cement shell in the loading axis of the implant to the position of the 25 ° angle (the position of mount stairs);

Our study shows that:

- The presence of a crack in the cement may break by opening her lips (mode I) and shear (Mode II) that is to say, in mixed mode, regardless of the type of interaction;

- The risk of rupture to the interaction of cracks in the third case, is higher than in other cases

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