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Numerical analysis of surface cracks of spherical explosive with a cushion

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Explosive components are widely used in military engineering. In view of the characteristics of the crack in the explosive component, the stress intensity factor and the J integral of the PBX component were studied. This paper studies the mechanism of crack damage under different conditions. The results show that the shape of the crack opening at different position of the components is different, together with the crack strength.

The crack intensity factor will be affected by the location of the crack, crack length, crack depth and crack direction. The study of the explosive components provides engineering with theoretical support.

Keywords*:* PBX Explosive, Crack, Stress Intensity Factor, J Integral, Gap Contact

INTRODUCTION

The explosive components in nuclear structure are an important component of the explosive detonation structure. The main component of the explosives is Octogen (HMX), which is a white crystal with the chemical formula $C_4H_8N_8O_8$. The chemical structure is shown in Fig1.

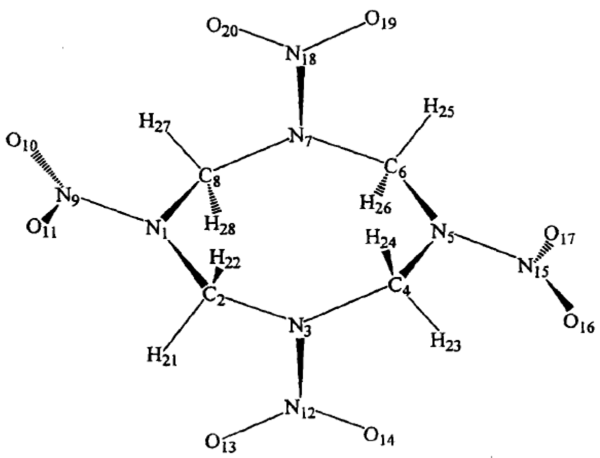

Fig.1. Schematic diagram of the chemical structure

The PBX explosive is formed by the main component and the binder. Under the action of the stress of the structure of PBX, it is easy to crack, which directly affects the performance of the explosive component. Therefore, it is necessary to study the mechanical properties of the explosive component. This article discusses the studies of the law of the crack of the explosive component.

ANALYSIS OF THE INFLUENCE OF THE CRACK ON THE EXPLOSIVE COMPONENTS

Analysis of conforming spherical contact

Study on the interaction of multiple cracks

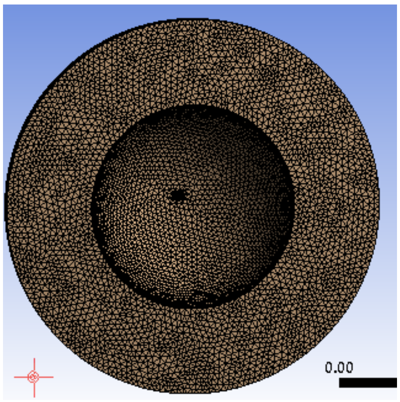

Fig. 1. One crack

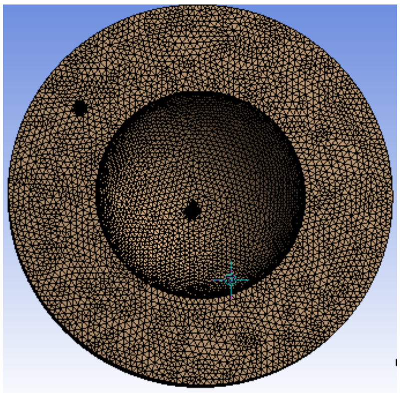

Fig. 2. Two cracks

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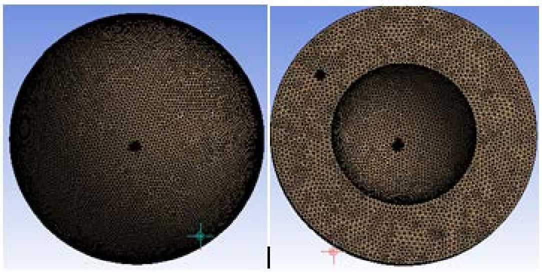

Fig. 3. Three cracks.

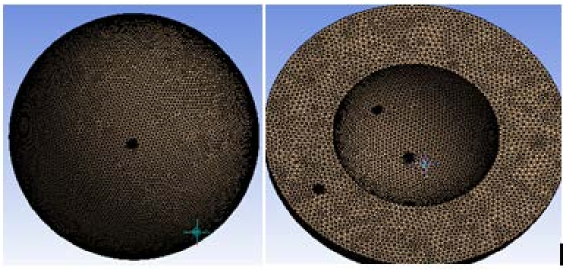

Fig. 4. Four cracks.

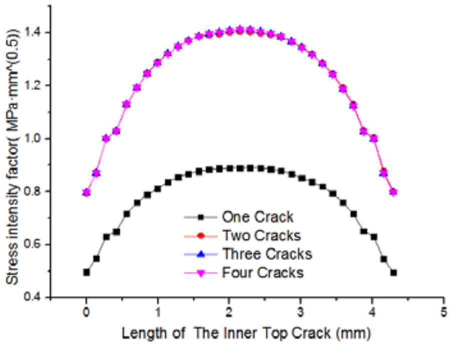

Fig. 5. K1 of stress intensity factor.

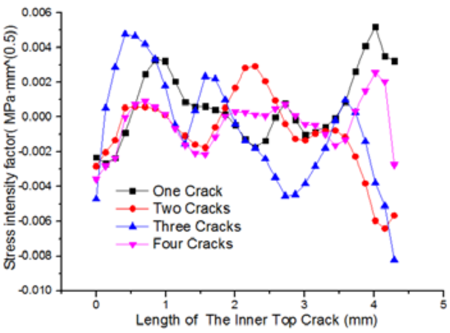

Fig. 6. K2 of stress intensity factor.

Figures 1 to 4, respectively illustrate one to four cracks. It can be seen from the picture, that stress intensity factors are not the same when the surface of an explosive component is subjected to one crack or a plurality of cracks. As observed in Fig.5 to Fig.8, when the explosive component is affected by the two cracks, the K1 influence factor of the crack on the top of the explosive component is different. When the number of cracks increase the stress intensity factor is not significantly different. The stress intensity factor K2 is similar to the starting position, but the strength of the crack is very different in the end position. At the same time, the stress intensity factor K2 and K3 can be seen to be a wave shape fluctuation from Fig. 6 and Fig. 7. The figures show that the sliding force and tearing force of the crack are more complex. As can be seen in Fig. 8, the J-integral of the crack has the same trend for the stress intensity factor.

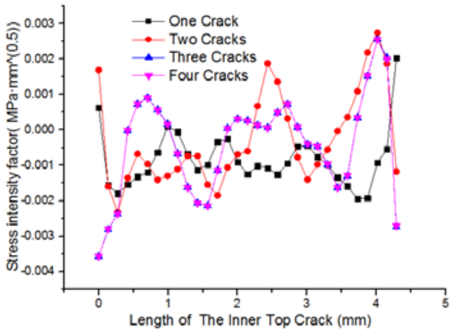

Fig. 7. K3 of the stress intensity factor.

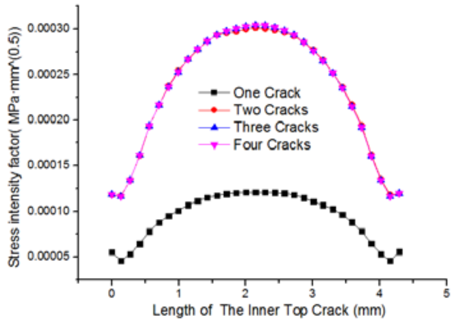

Fig. 8. J-integral

Cracks on the inner surface or outer surface of the explosive without a cushion

It can be seen from Fig.9, that the stress intensity factor at the top of the inner and outer surface is negative, so the crack is in the closed state and is not extended. Observing the stress amplitude, the stress intensity factor of the inner surface is greater than that of the outer surface and illustrates that the force of the inner surface is greater than that of the outer surface.

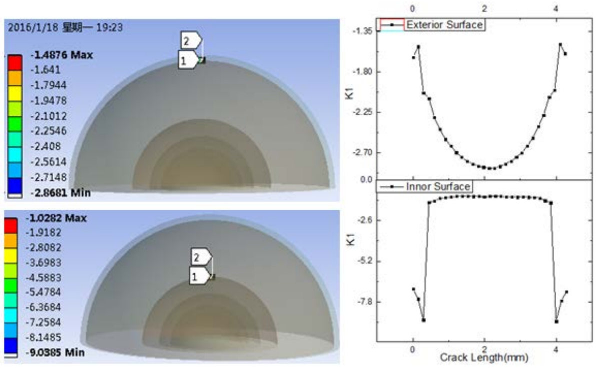

Fig. 9. Cracks on the inner surface or outer surface and the stress intensity factor

The stress intensity factor on the inner surface of the top appeared suddenly changed and the crack stress of the inner surface appeared attenuated at the middle of the crack length. The more closed the joint forces are at both ends of the crack, the more the crack will not occur.

Study on the influence of the crack parameters along with the change in crack length

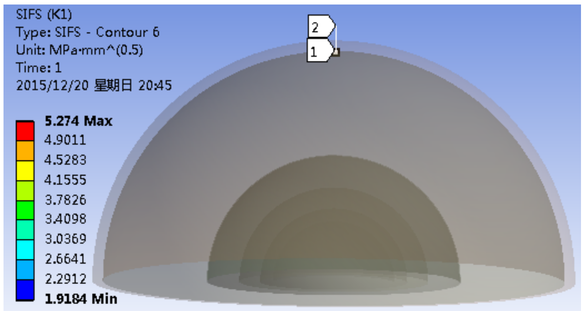

Fig. 10. A crack at the top of the explosive.

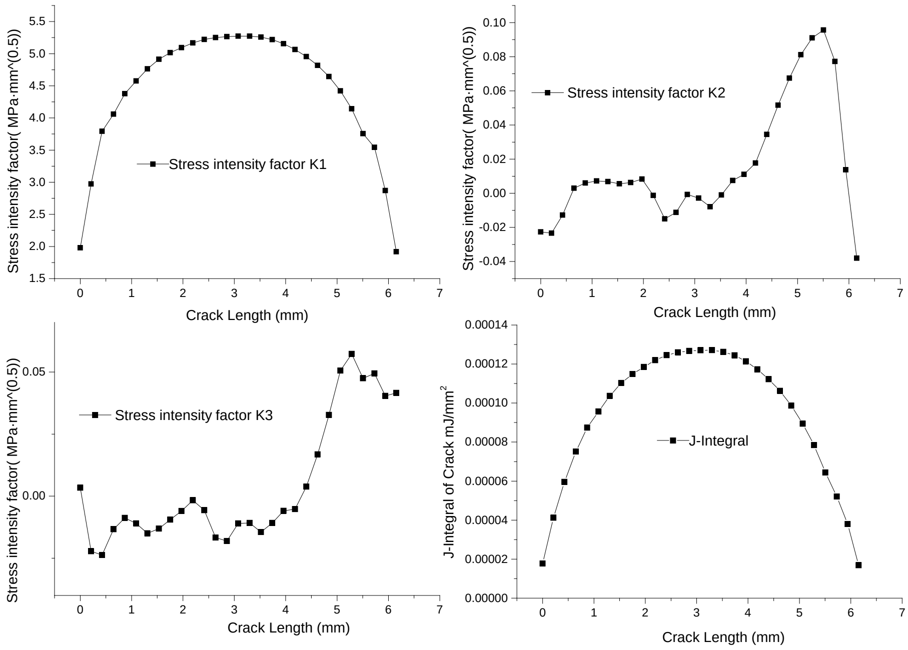

Fig. 11. The major axis radius is 3mm.

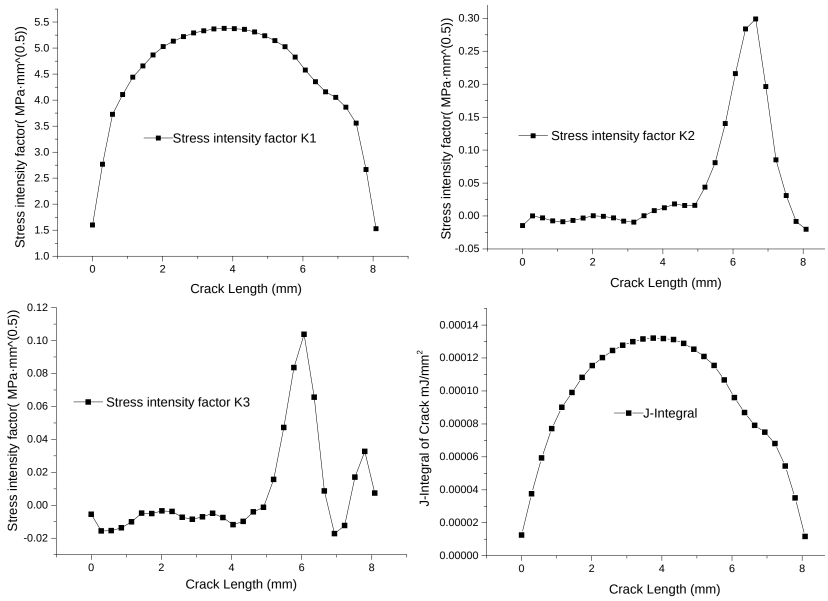

Fig.12. The major axis radius is 4mm.

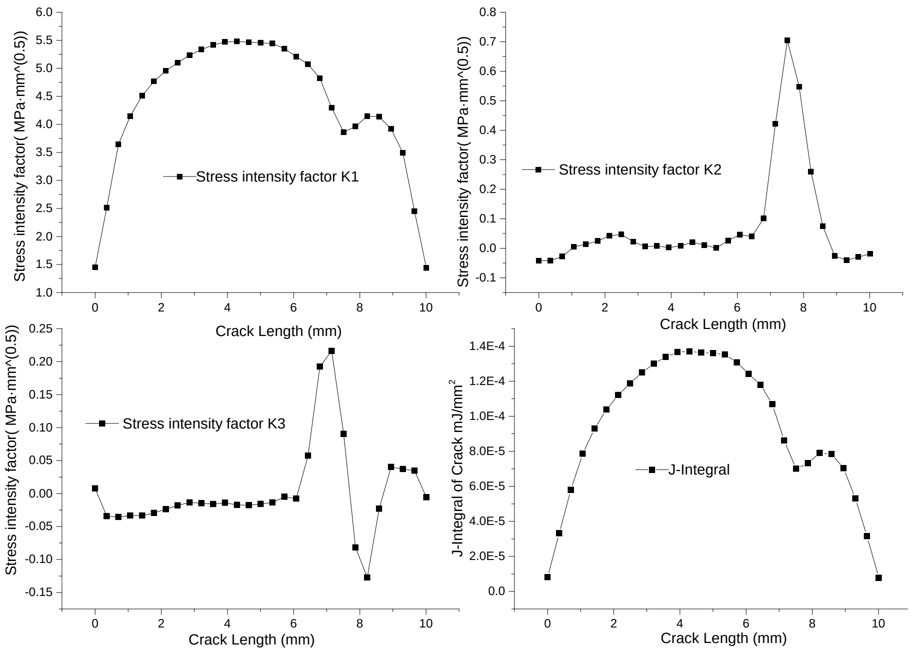

Fig. 13. The major axis radius is 5mm.

The analysis of this section is the case of the outer surface of the explosive component with a cushion layer without a clearance and contact. The crack is located outside the top of the explosive component and the crack length is 3mm, 4mm, 5mm, respectively. Seen in Fig. 11 to Fig.13, the stress intensity factor and J-integral will change along with the length of the crack. With the crack length increasing, the stress intensity factor K1 at some crack positions appear attenuated, meanwhile with the length of the crack increasing the stress intensity factors K2 will increase a lot. The stress intensity factor K3 change is not too obvious and the J- integration curve and the K1 curve are consistent.

Analysis of the influence of the crack parameters along with the depth of the inner surface

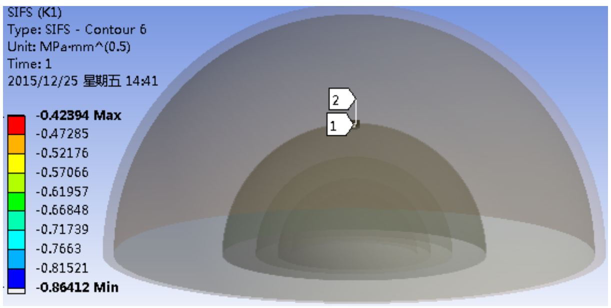

Fig. 14. The location of the crack.

The crack is located at the top of the inner surface of the explosive component without a cushion layer. The locations of the three cracks are as follows: at a depth of the top of the inner surface of the explosive component, at a depth of the inner surface of the explosive component below 1mm and at a depth of the surface of the explosive component below 2mm.

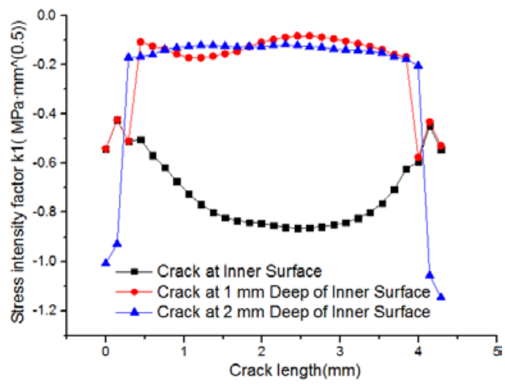

Fig. 15. The stress intensity factor K1 along with the depth.

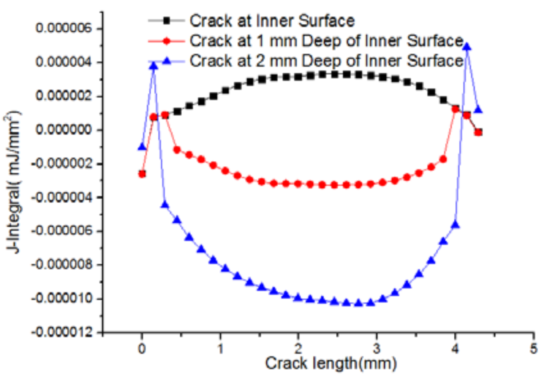

Fig. 16. The J-integral at a differnt crack depth.

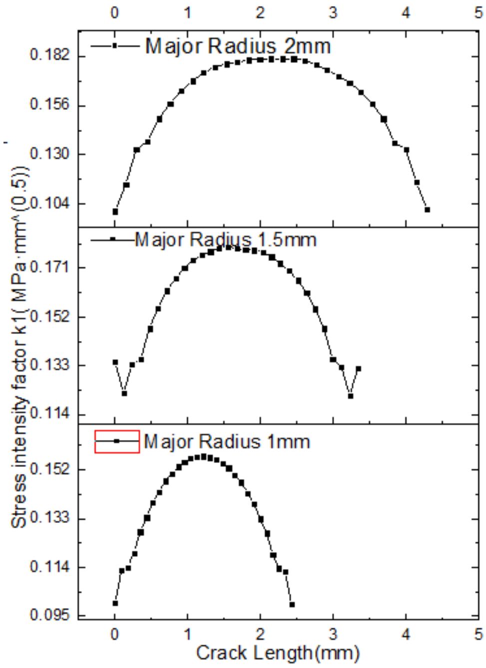

Fig. 17. Stress intensity factor K1.

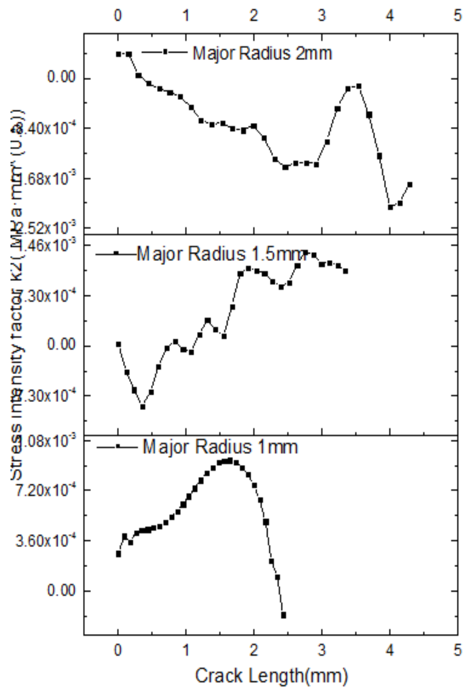

Fig. 18. Stress intensity factor K2

The crack stress intensity factor and J integral are different in three different depths from Fig.15. Generally speaking, the stress intensity of the crack on the surface is greater than the stress intensity factor of the crack at a depth of 1mm and 2mm. As can be seen from Fig.16, the J-integral of the surface crack is greater than that at a depth of 1mm, and the J-integral at the depth of 1mm is greater than that at a depth of 2mm. From Figure 15 and Figure 16 we observe, that the stress of the surface crack is greater than that of the internal crack.

Analysis of the surface crack of a sphere with a clearance contact

Stress intensity factor analysis without a cushion

Effect of the crack length on the stress intensity factor of the inner surface top of the explosive

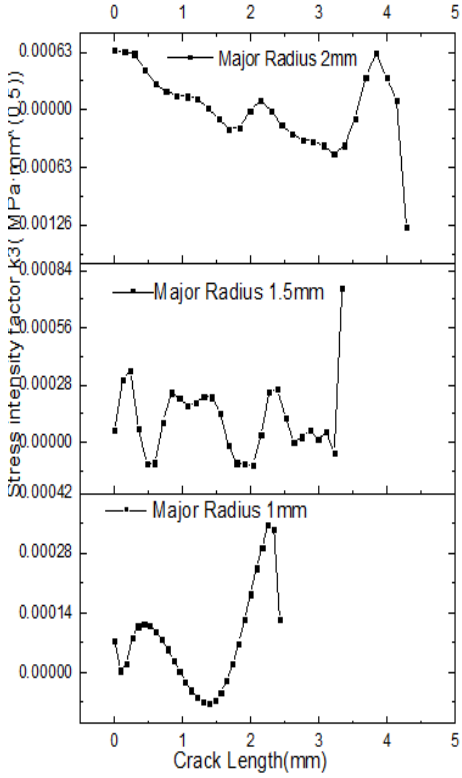

Fig. 19. Stress intensity factor K1.

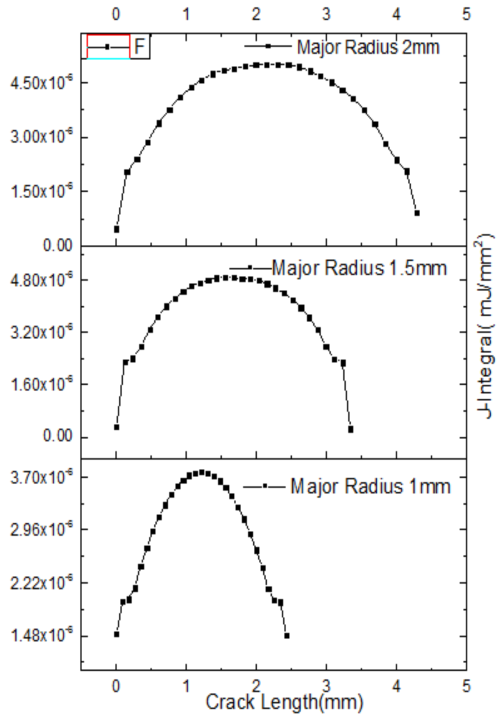

Fig. 20. J-integral.

Effect of crack length on the stress intensity factor of the outer surface top of the explosive

From Fig.21 compared with Fig.21, the stress intensity factors at major radii of 2mm, 2.5mm, 3mm and 3.5mm of the outer surface crack are much larger than those for radii of 1mm, 1.5mm and 2mm. Because there is no cushion on the outer surface to protection the crack, the stress intensity factor of external surface cracks is much larger than that of the inner surface crack. The stress intensity factor of K2 and K3 increases with the increase of crack in length.

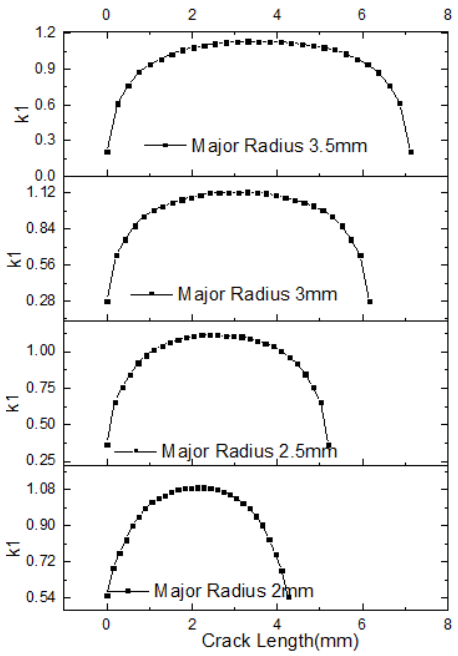

Fig. 21. Stress intensity factor K1.

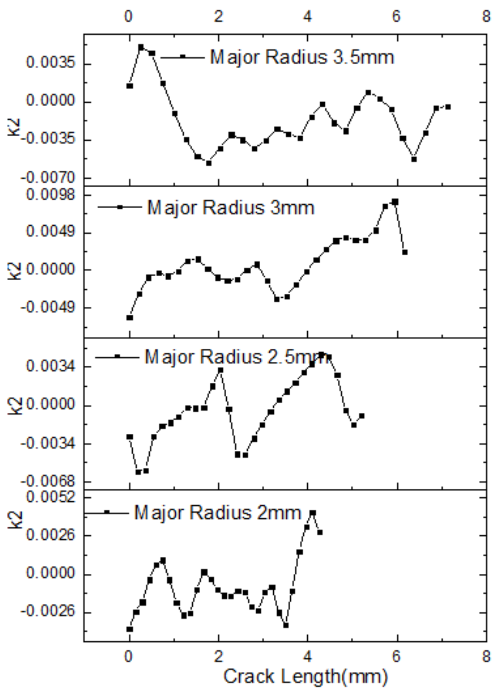

Fig. 22. Stress intensity factor K2.

Analysis of the stress intensity factor of the crack of the inner surface along with the depth

The cracks at four different depths (0mm, 0.5mm, 1mm, 1.5mm) were analyzed in this case. It can be seen that the crack stress intensity factor decreases with the increase in depth of the crack. Especially, when the crack depth is 1mm and 1.5mm, the stress intensity factor attenuation is especially obvious. At the same time, with the increase of depth, the stress intensity factor K2 and K3 also have different degrees of attenuation.

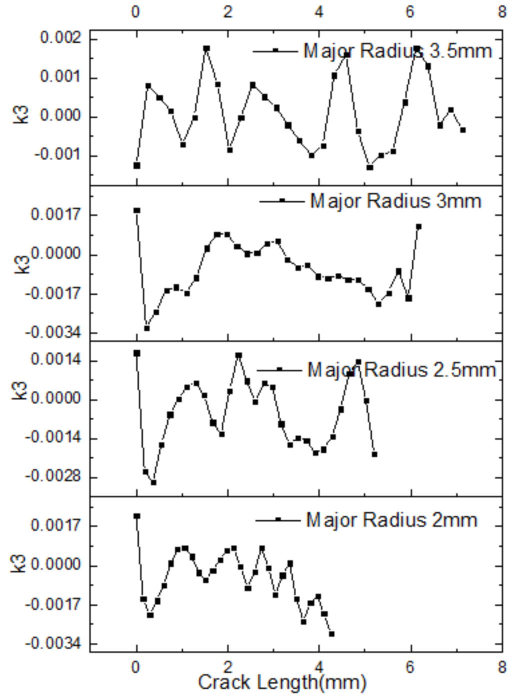

Fig. 23. Stress intensity factor K3.

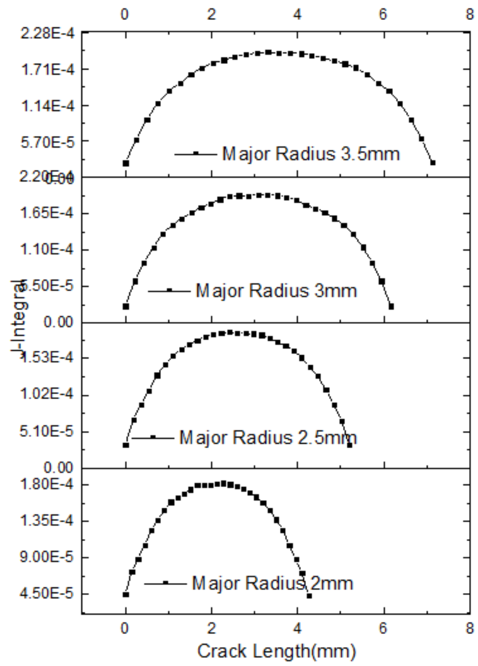

Fig. 24. J-integral.

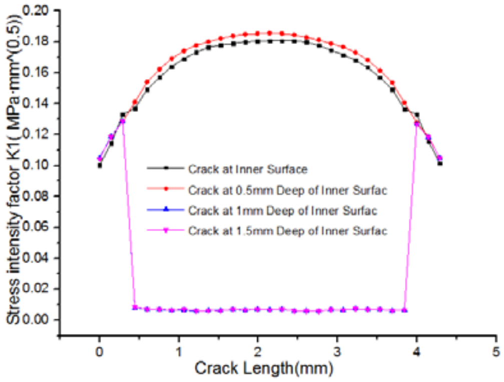

Fig. 25. Stress intensity factor K1.

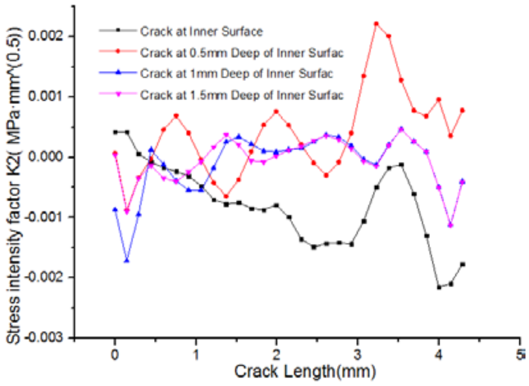

Fig. 26. Stress intensity factor K2.

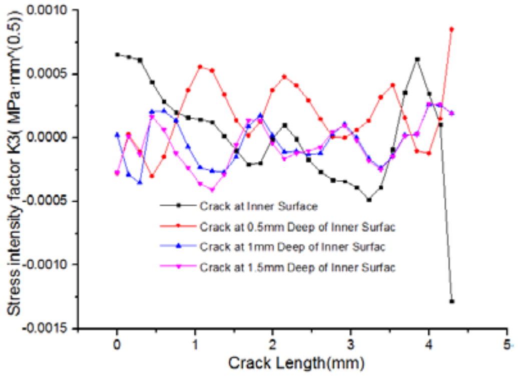

Fig. 27. Stress intensity factor K3.

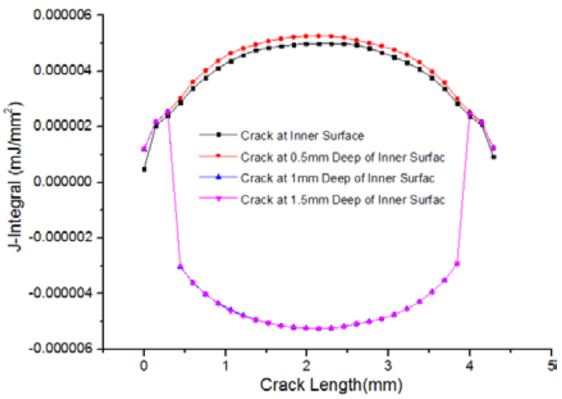

Fig. 28. J-integral

Analysis of the stress intensity factor of the crack on outer surface along with the depth

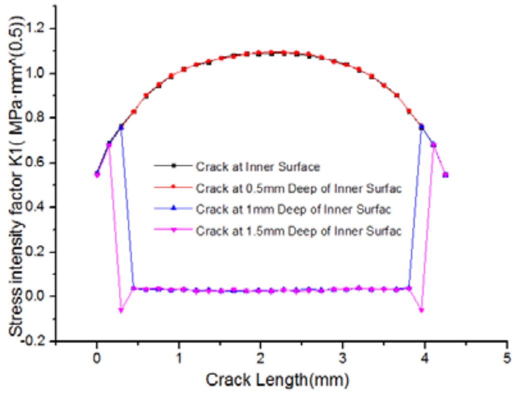

Fig. 29. Stress intensity factor K1.

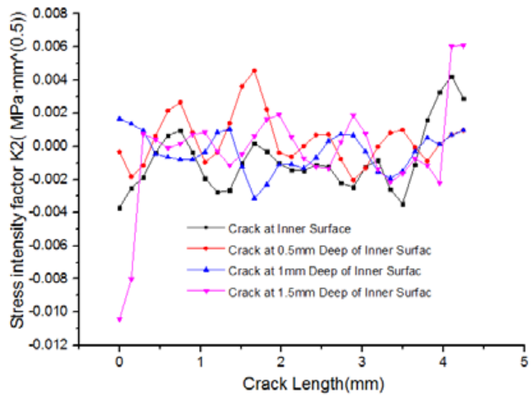

Fig. 30. Stress intensity factor K2.

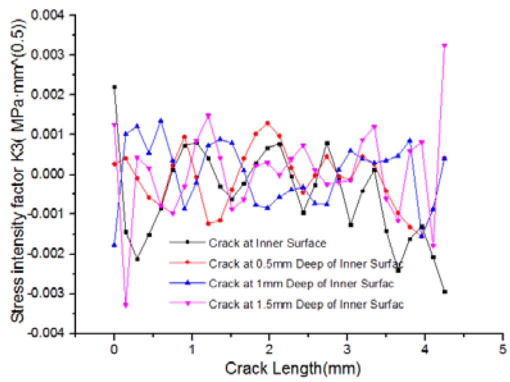

Fig. 31. Stress intensity factor K3.

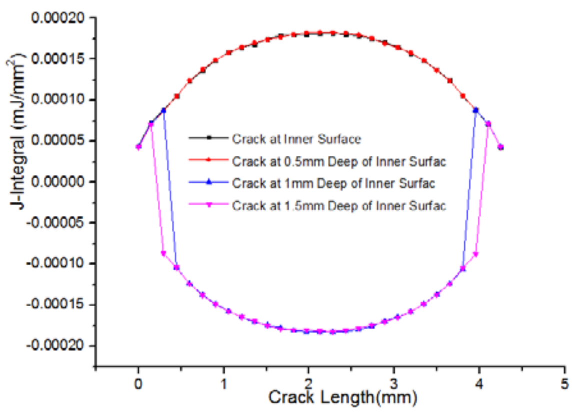

Fig. 32. J-integral.

Compared with the stress intensity factor of the inner surface, the stress intensity factor of the outer surface is very different. First, the stress intensity factor increases, because there is no cushion on the outer surface. When the outer surface of the metal shell is constrained, the stress intensity factor is larger than that of the inner surface; Second, after the depth of the crack below the surface is increased, the intensity factor of the crack is reduced. The stress intensity factor is especially obvious when the crack depth is 1mm and 1.5mm. On the whole, the crack parameters of the outer surface are very similar to the inner surface crack parameters.

Stress intensity factor analysis with a cushion

Analysis of the stress intensity factor of the crack of the outer surface along the depth

The stress intensity factors K1, K2, and K3 are shown in Fig.34 to Fig.36, where the locations are at the outer surface of the top surface depths of below 1 mm, 2 mm and 6 mm of the explosive component crack with a cushion. As can be seen, attenuation suddenly appeared at the stress intensity factor of K1. It can be seen that the deeper the crack is below surface, the smaller the stress intensity factor is. At the same time, it can be seen that the stress intensity factor with the cushion is smaller than that of the stress intensity factor without a cushion given the crack is in the same place.

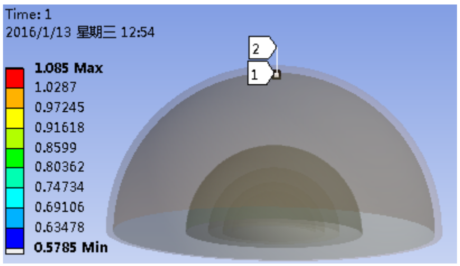

Fig. 33. The crack location.

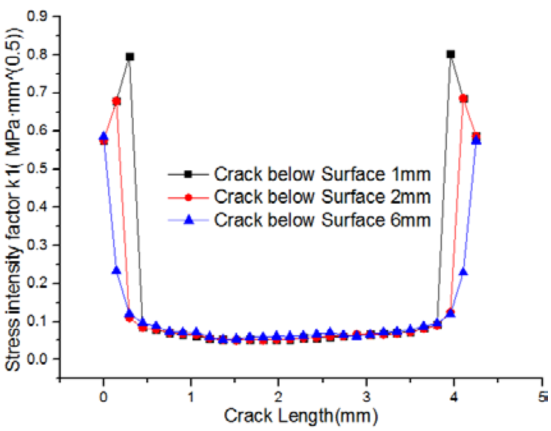

Fig. 34. Stress intensity factor K1.

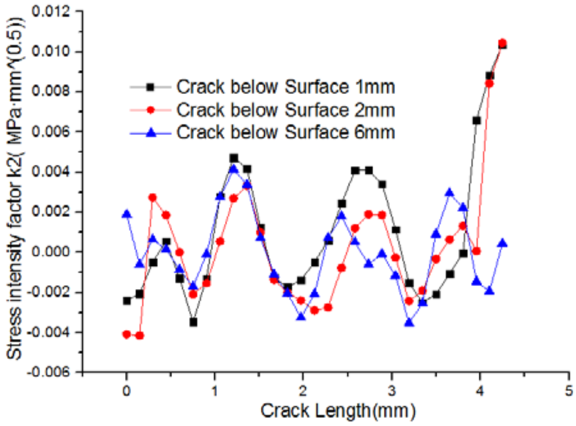

Fig. 35. Stress intensity factor K2

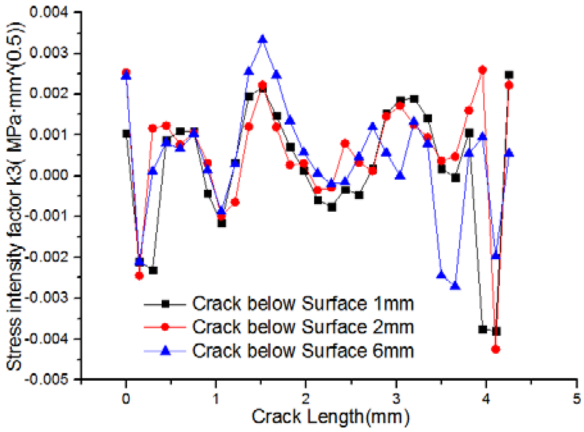

Fig. 36. Stress intensity factor K3

Crack at the bottom of the explosive component near the outer steel shell

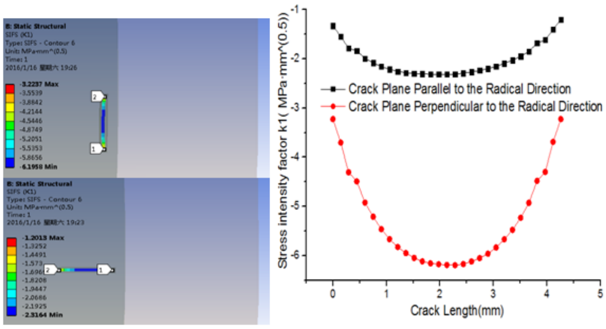

Fig. 37. Two cracks at different directions and the simulation results.

It can be seen that the stress intensity factor is less than zero in two directions, indicating the cracks in the closed state. But the stress intensity factor in both directions vary greatly in size, the stress intensity factor perpendicular to the radial direction is greater than that parallel to the radial cracks. The simulations show that the cracks are perpendicular in the radial direction rather than parallel to the radial cracks and are more susceptible to the effect of the closing force.

A crack at the bottom of the explosive component near a cushion

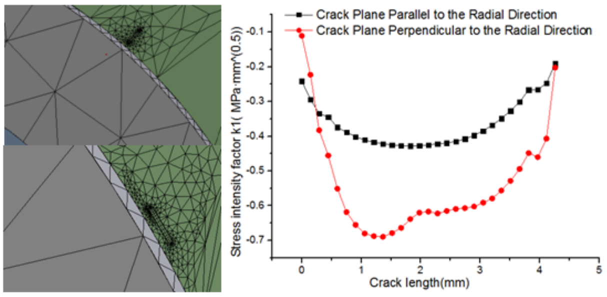

Fig. 38. Two cracks at different directions and simulation results.

The above simulation is the stress intensity factor K1 of the bottom of the explosive component without gap contact. Compare Fig.38 with Fig.37, the stress intensity factor of outer surface crack is much larger than that of the inner surface crack. It can be seen that the cushion has a very good protective effect on the explosive components.

A crack at the bottom of the explosive component near the cushion with a gap contact

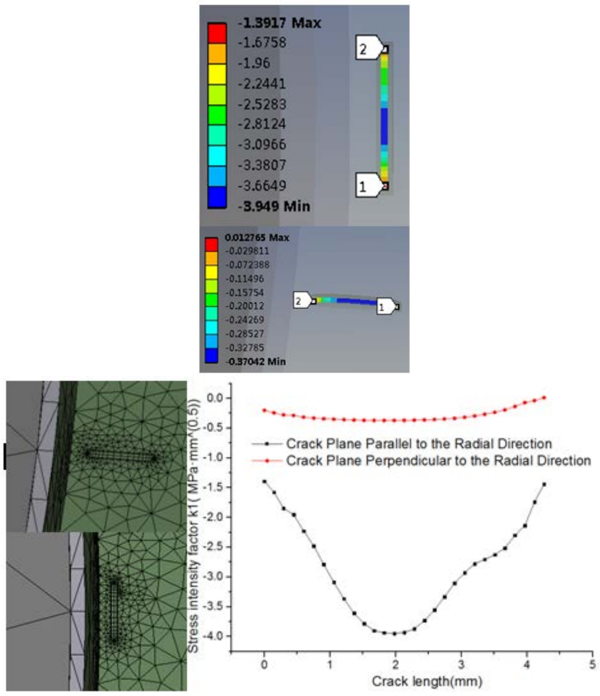

Fig. 39. Two cracks in different directions and the simulation results.

The stress from the crack can be observed with the stress in parallel direction to the radial crack being much larger than the stress perpendicular to the radial crack. Comparing Fig. 38 with Fig.39 shows that the stress of the radial crack is very different for the two contact states. This is the reason that the crack in the radial direction is the most susceptible to the thermal stress caused by the heat released from the nuclear components. When the initial boundary conditions are set, the bottom surface is fixed in the Y and X directions, so the crack can't be displaced in the plane direction. Since the crack is not moving in the plane direction, the crack is in a closed state.

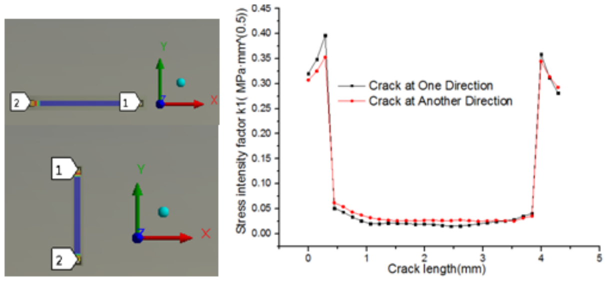

Fig. 40. Two cracks at different directions and simulation results.

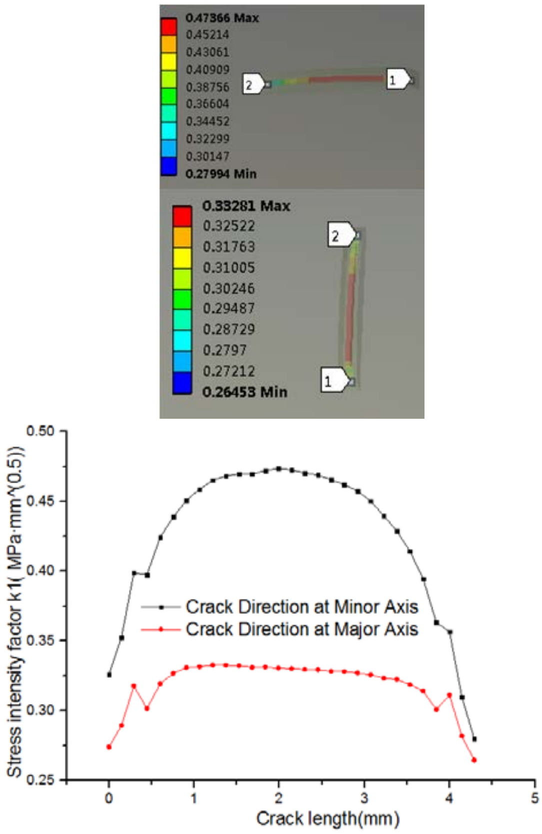

Fig. 41. Two cracks at different directions and simulation results.

A crack at the top of the outer surface of the explosive in two vertical directions

Through the analysis of the external surface crack of the explosive components, it can be seen that the stress intensity factor curve of the two kinds of cracks is similar, which shows that the stress characteristics of the two kinds of cracks on the outer surface are relatively close. It can be seen that the stress intensity factor K1 of the crack on the outer surface is greater than zero, which indicates that the crack in the outer surface is affected by the opening force. Between 0.4 mm and 4 mm in length, the two kinds of crack intensity factors have a mutation, which shows that the stress is relatively small between 0.4 mm and 4 mm.

A crack at the top of the inner surface of the explosive in two vertical directions

There are differences between the stress intensity factors of the cracks in the two directions at the top of the inner surface. The crack intensity factor in the direction of the short radius is larger than that in the direction of the long radius. This shows that the intensity factor of the crack with a gap is larger than that without a gap. In accordance with Fig. 40 and Fig. 41 the outer surface of the crack occurred mainly due to the simulation of the crack being too long and the stress not enough to support the stress in such a long crack.

CONCLUSION

1 After adding a crack, first the crack stress intensity factor will obviously increase. Continuing to increase the cracks, the stress intensity factor did not change significantly.

2 Under the same condition, the stress intensity factor at the inside and outside surface is not the same. The stress intensity factor at the inner surface is larger than that at the outer surface and the stress intensity factor in the middle of the crack at the outer surface appears a "broken" phenomenon.

3 Once the crack length increases, the crack intensity factor K1 can be mutated. It is shown that the stress of the crack is not enough to support the crack at the corresponding length, so the length of simulation assumes that the crack should shorten.

4 The stress intensity factor K1 of the cracks in the two perpendicular directions at the inner top surface of the explosive with a clearance in contact is different. Generally speaking, the crack stress intensity factor which is perpendicular to the radial direction is larger than that which is parallel to the radial direction.

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ЧИСЛЕН АНАЛИЗ НА ПОВЪРХНОСТНИ ПУКНАТИНИ ПРИ СФЕРИЧНИ ЕКСПЛОЗИВИ С АМОРТИСЬОР

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(Резюме)

Експлозивите се използват широко във военното инженерство. Тук са изследвани характеристиките на пукнатините в експлозивите, факторът на интензивност на напрежението и J-интеграла на PBX-компонентите. Изследван е механизмът на влияние на пукнатините при различни условия. Резултатите показват, че формата на пукнатината при различно положение на компонентите е различна, заедно със здравината на пукнатината.

Факторът на интензивност зависи от положението на пукнатината, дължината, дълбочината и направлението й.