The Measurement of Dynamic Fracture Toughness CTOD

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ABSTRACT

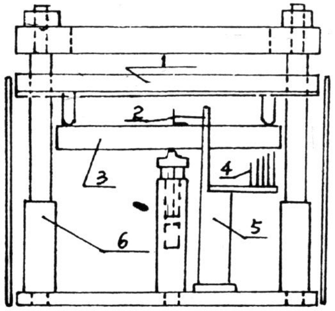
The dynamic fracture toughness CTOD of ductile material under the explosion impact loading was investigated using the three point bend specimen in our experiment and it can be obtained by measuring the crack propagating procedure, the rotation angle of specimen and the surface opening displacement of the crack at the same time. The crack propagation was measured by using the indirect potential method and the rotation angle of the specimen and the surface opening displacement of crack were measured by the method of electric probes. The experimental results showed that under the explosion impact loading the crack propagating speed is the largest at its initial propagating and then it decreases rapidly along with the crack propagation. The dynamic fracture toughness of ductile material CTOD will become small when the rate of crack propagation is high, specially the initial crack propagating speed is large.

1. INTRODUCTION

To measure the dynamic fracture toughness of materials is always a very important and difficult subject of dynamic fracture mechanics. This problem has met with success in liner elastic dynamic fracture mechanics, the caustics method has been presented to measure the dynamic fracture toughness k_{1d} of liner elastic materials(1). Recent years, many scholors also work at the experimental study of dynamic fracture toughness CTOD(2)(3). But main works are limited at the brittle fracture of liner elastic materials or the infinite deformation elastic plastic fracture. Now few persons have been inverstigated the dynamic fracture toughness CTOD for the dynamic plastic fracture under large plastic flow and the effective experimental methods even more have not been seen. The method of section metallograph was presented to observe the remnant CTOD of ductile materials in reference (4) and it stipulates that the dynamic fracture toughness of ductile materials CTOD is taken as the CTOD where the crack is just initial propagating and has not propagated further. In fact, if the crack propagates rapidly the dynamic fracture toughness CTOD will change and decrease. So just using the section metallograph to study the dynamic fracture toughness of ductile materials is not enough, and we need to investigate that under the different rate and amplitude of loading, the dynamic fracture toughness of ductile materials is how to change and has what relationship with the crack propagating speed. In this paper, a new experimental method to study the dynamic fracture toughness of ductile materials was presented and the three point bend specimen made of low-carben steel was used in our experiment, where the explosion impact loading was taken.

2. THE EXPERIMENTAL DESIGN

Because our experiment is mainly to study the fast stable propagation of crack in large plastic flow field, so a ductile material--low-carben A3 steel was selected as the material of specimen and its static yield stress is 2300 kg persquare centimeter. The three point bend specimen was used in our experiment and the loading is explosion impact load. The loading equipment is shown in Fig.1 and the explosive explodes over the equipment and the burst wave affects on the sliping plate and push it down, then through two supports the force is added on the specimen. The specimen size is $220\times10\times25$ mm^3, its length direction is perpendicular to the rolling direction and its height direction is the direction of the plate thickness.



1.Sliping plate
2.Horizontal probes
3.Specimen
4.Vertical probes
5.Probes support
6.Slide-bars

Fig.1. The experimental equipment

The indirect potential method was used to measure the crack propagating speed. Because the large plastic deformation would take place in the crack tip of specimen before it fractures, therefore the crack gage must be ductile enough to ensure that it will fracture synchronously with the specimen and also the glue that sticks the gage must have enough ductility and strength, so that the gage and the specimen would become one unit and could not seperate before fracture. As we know, if the crack propagating length, the rotation angle of specimen and the surface opening displacement of the crack were known in the fracture procedure, then the dynamic fracture toughness CTOD can be obtained by the relations of geometry. Therefore the electric-probes were used to measure the specimen rotation angle θ and horizontal opening displacement x of the crack surface, it is shown in Fig.2.

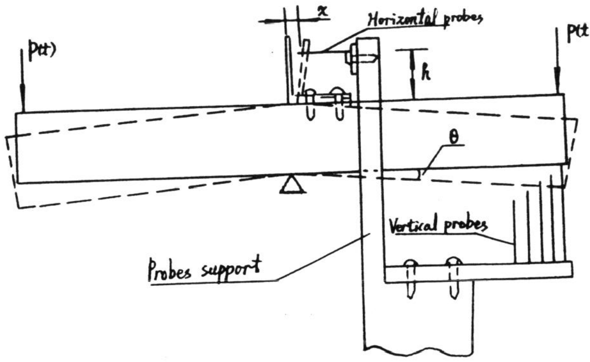


Fig.2. The arrangement of probes

The vertical probes was used to measure the rotation angle of specimen and the horizontal probes to measure the crack opening distance. For that, an angle aluminium was fixed on the specimen near the crack, when the angle aluminium rotates following the specimen and touches the horizontal probes, the contact outputs of probes can be presented. In the same, when the specimen moves and touches the vertical probes, the contact outputs will be given.

All the outputs in the experiment were shown by oscillographs and photographed. The oscillographs were touched off by the same trigger in order to ensure synchronism in the time.

3. EXPERIMENTAL RESULTS AND ANALYSIS

The probes arrangement of two groups experiment and its contact time were shown in Table 1, where the time of appllied force initial effect was taken as the zero point of time, h is the distance between the horizontal probes and the specimen, x is the horizontal distance from the horizontal probes to angle aluminium, y is the vertical distance from the vertical probes to the specimen, Ly is the distance from the vertical probes to the rotation center of specimen and $\theta = y/Ly$ is the rotation angle of specimen.

The signals record of the first group experiment was shown in Fig.3. They are (a) the horizontal probes signals (b) the vertical probes signals, (c) the voltage output of the crack gage and (d) the output of the force transducer.

Table 1. The probes arrangement and the contact time

	NO.	x(mm)	h(mm)	t_x(ms)	y(mm)	Ly(mm)	$\theta \times 10^2$	ty(ms)
	1	0.1	14.5	0.287	0.65	98	0.66	-0.45
First	2	0.3	14.5	0.340	1.70	93	1.83	0.265
Group	3	0.75	14.5	0.886	2.60	88	2.95	0.571
Experiment	4	1.04	14.5	1.109	3.20	83	3.86	0.907
	5	1.50	14.5	1.609	4.40	78	5.64	1.587
	1	0.1	14.5	0.13	0.5	98	0.51	0.014
Second	2	0.2	14.5	0.21	0.9	93	0.97	0.244
Group	3	0.4	14.5	--	1.4	88	1.60	0.424
Experiment	4	0.65	14.5	1.03	2.1	83	2.53	0.764
	5	0.9	14.5	1.15	3.0	78	3.8	1.244

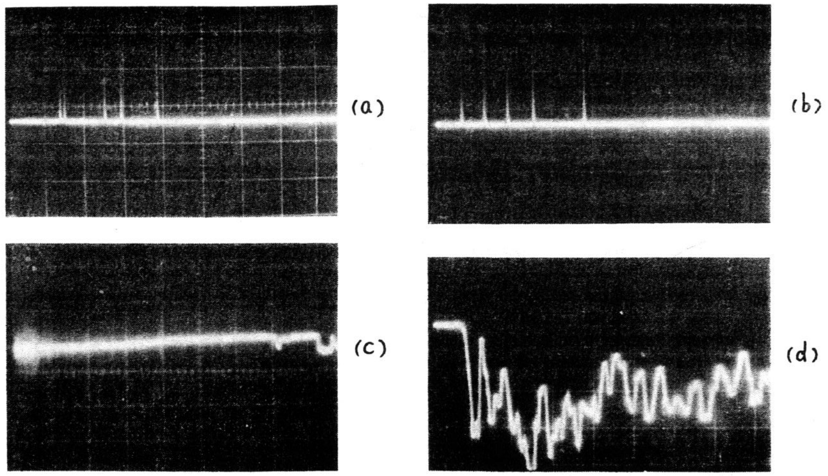
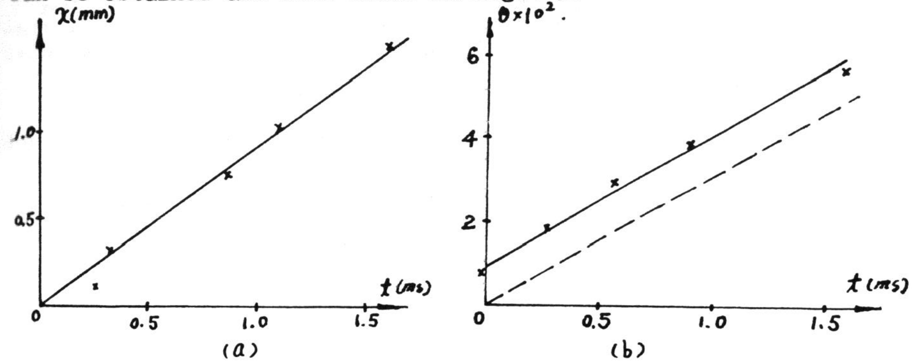


Fig.3. The experimental signals for one group (0.5 ms per check), (a) horizontal probes signals. (b) vertical probes signals, (c) voltage output of crack gage and (d) output of force transducer

Put the experimental results shown in Table 1 on the x-t plane and the θ-t plane, the curves of the crack opening displacement x and the rotation angle of specimen θ changed with the time can be obtained and were shown in Fig.4-5.



(a) (b)

Fig.4. The first group experimental results, (a) the horizontal opening displacement measured by horizontal probes, (b) the rotation angle of specimen

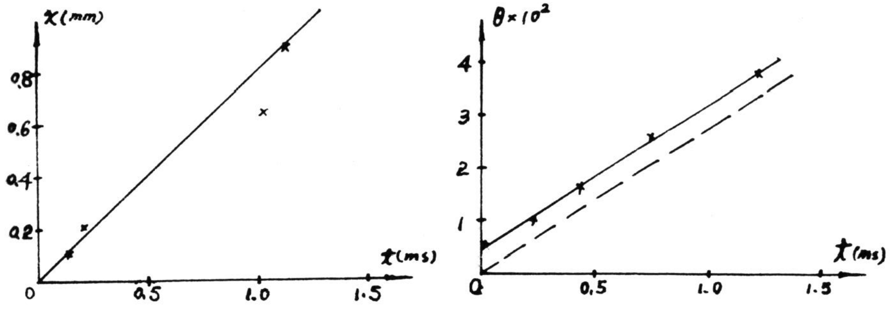


Fig.5. The second group experimental results,(a) the horizontal opening displacement measured by horizontal probles,(b) the rotation angle of specimen.

From Fig.4 and Fig.5, we can see that the lines x-t are through the origins of coordinates. It means that the horizontal opening displacement of the crack is caused by the plastic rotation of specimen under the effect of applyed force. Because the applyed force was transmited to the force transducer by the specimen, so if there are any elastic deformation to cause the crack opening, it must be happened prior to the signal of force transducer. So it also means that the whold fracturing section of specimen came to yield simultaneously, under the high amplitude explosion load, therefore the concept of elastic CTOD is unsuitable here or it can be seen that the elastic CTOD is equal to zero.

From Fig.4(b) and Fig.5(b), we can see that the lines θ-t didn't pass the origins of the coordinates and it means that the specimen had a certain displacement in the vertical direction before the applyed force transmites to the transducer. This displacement is caused mainly by the elastic deformation of specimen and perhaps including other factors. Because this part of vertical displacement does not cause the plastic rotation of specimen and should be eliminated in the calculation of CTOD, the exact plastic rotation of specimen should be the dashs lines shown in Fig.4 and Fig.5, which parallel to the solid lines.

Thus the CTOD, notes δ, and the plastic rotation factor r_p can be obtained by the geometry in all procedure of the crack propagation,

$$\delta = 2(x - \theta(h + a)) \qquad (1)$$

$$r_p = \frac{\delta}{2\ (H - a)\theta} \qquad (2)$$

where a is the crack length and it can be represented as

$$a = a_0 + w \frac{\Delta V}{V_0 + \Delta V} + \Delta a \qquad (3)$$

where w is the width of the crack gage, ΔV is the voltage increasing output of the gage caused by crack propagating, V_0 is the initial voltage output of the gage and Δa is the revision quantity of the mid-crack of specimen,

$$a = \begin{cases} a_s \dfrac{\Delta}{\Delta a_e} & a_s < \Delta a_e \\ \Delta & a_s \geqslant \Delta a_e \end{cases} \qquad (4)$$

where a_s is the crack surface propagating length and $a_s = w \frac{\Delta V}{V_0 + \Delta V}$, Δ is the difference of the final crack length between the mid-crack and the surface crack, Δa_e is the crack surface propagating length when the tear fracture near the surface of specimen reaches its most width. Δ and Δa_e can be obtained from the fractures of specimens after the experiment.

According to the equations (3) and (4), the crack propagating length and the rate of crack propagation can be given as the function of time, they were shown in Fig.6 and Fig.7.

Substituting the results shown in Fig.4 to Fig.7 into the equations (1) and (2), the CTOD and the plastic rotation factor r_p in all fracture procedure can be obtained and they were

shown in Fig.8 and Fig.9 as the function of the crack propagation.

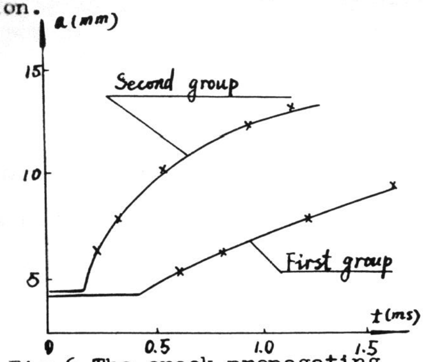


Fig.6 The crack propagating lengths of two group experiments

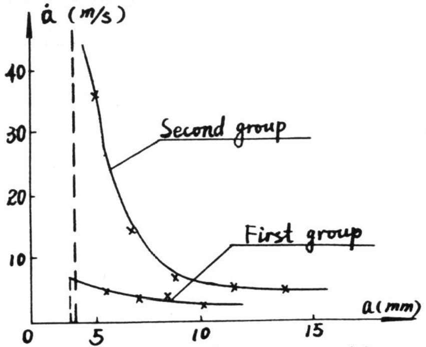


Fig.7 The crack propagating speeds of two group experiments

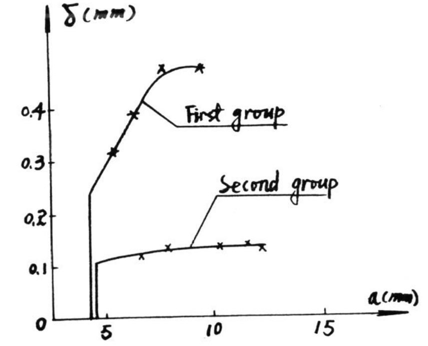


Fig.8 The changes of CTOD in the procedure of crack propagation.

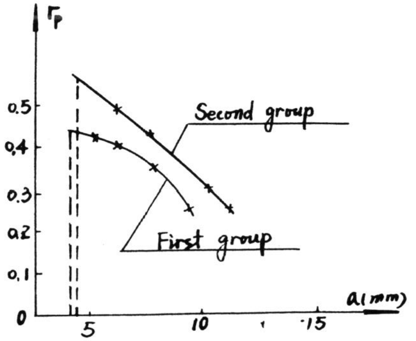


Fig.9 The changes of plastic retation factor in the fracture procedure.

From Fig.8, we can see that there is a world of difference between the two groups of experiment for the dynamic fracture toughness of material. The fracture toughness of material CTOD in the first group is less than the fracture toughness in the second group, because the crack propagating speed in the first group experiment is larger than that in the second group. So the dynamic fracture toughness of ductile material is affected greatly by the crack propagating speed. On the other hand, for one group experiment, the fracture toughness CTOD increased along with the crack propagation, but the increase of CTOD in the fracture procedure is not only related to the crack propagating speed, but also related to the crack initial propagating speed. From Fig.9, we can see that at the crack initial propagating the plastic rotation factor r_p is almost the same as the results of static experiment, about 0.45, but it decreases quickly along with the crack propagation. This phenomenon means that there was an axial fracture force at the crack tip in the fracture procedure, this fracture force made the rotation center of the specimen fracturing section change.

CONCLUSION

To measure the dynamic fracture toughness CTOD of ductile materials is possible and effective using the method presented in this paper. The dynamic fracture toughness of ductile materials is different for the different crack propagating speed and it becomes much less than its static value under the large crack propagating speed. For low-carben steel if the crack initial propagating speed is about fifty meters per second, then the CTOD will decrease to 0.1 mm and if the crack initial propagating speed is about five meters per second, then CTOD is about 0.25 mm, it is about the half of its static value. The crack propagating speed is not only related to the loading rate, but also related to the loading amplitude and its period.

ACKNOWLEDGEMENT

This experiment was halped by Mr. Chen Xue-Fen et al, the teachers of Explosion Mechanics Laboratroy of our university. We take this opportunity to express our sincere appreciation for their help.

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