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Dynamic Crack Propagation Analysis for Mild Steel Specimen

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연강 시험편에 대한 동적 균열 전파 해석

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Abstract Dynamic crack propagation in ductile steel is investigated by means of impact loaded 3 point bending specimens. The specimen has the size of 320x75 mm with a thickness of 10 mm. One static and two dynamic experiments with impact velocities of 30.2 m/s and 45.2 m/s are carried out. High speed photography is used to obtain crack growth and crack tip opening displacement data. Direct measurement of the relative rotation of the two specimen halves is made by using Moire interference pattern. The experiments indicate no or only a slight influence of the loading rate on the crack propagation.

요 약 연강에서의 동적인 크랙 전파는 충격 하중을 받는 3점 굽힘 시험편들에 의해서 연구되어진다. 시험편은 10 mm의 두께를 가진 320 x 75 mm의 크기를 가지고 있다. 하나의 정적인 실험과 30.2 m/s 및 45.2 m/s의 충격 속도들을 가진 두 개의 동적 실험들이 행하여진다. 고속 카메라는 크랙 성장과 크랙 선단 개구 변위들의 데이터를 얻는데 사용되어진다. 두 개의 반쪽 시험편들의 상대 회전을 직접 측정하기 위해서 Moire의 간섭 패턴을 사용한다. 실험들에서는 크랙 전파에 대한 하중 속도의 영향이 없거나 약간의 영향이 있는 것으로 나타나고 있다.

Key Words : Dynamic crack propagation, 3-point bend specimen, High speed photography, Crack tip opening displacement, Moire interference pattern

1. Introduction

This investigation is the second part of a study concerning criteria for crack initiation and crack propagation in a dynamically loaded ductile steel 3PB specimen. A preparatory theoretical study of the experiments[1][2] was first made by experiments and numerical simulation of dynamic crack initiation in microalloyed Manganese steel[3]. The experiments were made on 18 mm thick three point bend(3PB) specimens[4]. A prefabricated fatigue quarter width crack was made and the specimens were tested at 15, 30 and 45m/s impact velocity in the acceleration track test facility.

It was found that the specimen behavior is very much influenced of the boundary conditions between the hammer and the specimen at the impact points[3,5-8]. The ductile specimen deforms plastically where it is hit by the impact heads, especially at higher impact velocities. The circular shaped impact heads form circular indents, which in turn work as guides for the successive deformation of the specimen. The dynamic experiments were performed in the acceleration test facility. The experimental setup is shown in Fig. 1. The U-shaped hammer is accelerated to a prescribed velocity and hits the 3PB specimen at its ends. Two hardened and tempered impact heads with cylindrical contact surfaces are attached to the hammer. The dynamic experiments as presented here were carried out at the temperature of 18℃ and with impact velocities of 30.2 and 45.2 m/s. A quasi-static test was made with midpoint loading at a velocity of 50 mm/minute. The advantage of this loading system, is that the translation of the specimen midpoint area is kept as a minimum. This opens the possibility in closing up with high speed photography to record the crack propagation through the specimen.

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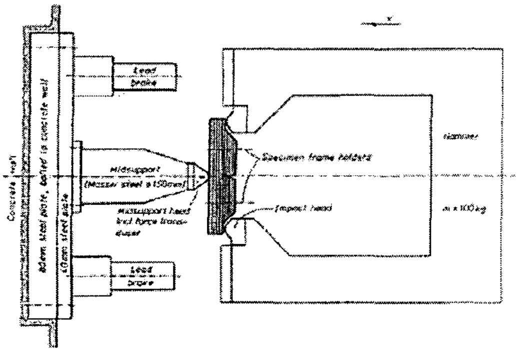

Fig. 1 The experimental display.

2. Experiments

The fracture surfaces obtained at these experiments was seen on the impact velocity of 15.02 m/s as seen in Fig. 2.

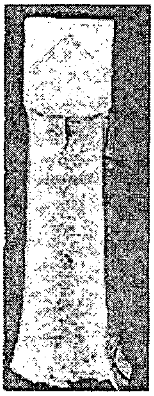

Fig. 2 The fracture surfaces obtained in 3PB specimen under the impact velocity of 15.02m/s.

A compressive force will be induced on the crack plane. The great difference of the specimen behavior for the two extremes, locking and roller conditions at the impact heads, was demonstrated[3]. Comparison between the experiments and simulations showed that such restrictions were present. The crack is thus closed initially when the classical 3PB specimen design is used.

The conditions at the impact heads are difficult to quantify and it was therefore decided to redesign the specimen in order to avoid the compressive loading during the initial phase of the impact. The new design is shown in Fig. 3.

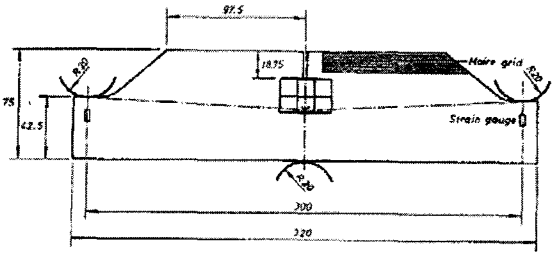

Fig. 3 Dimensions of the new designed 3PB specimen. All dimensions are in mm.

The specimen width is reduced at the ends. The relative motion of the two specimen halves follows approximately the motion of the two marked point lines. The impact points and the center of rotation of the two specimen halves lie almost on a straight line on the condition that no compressive loading of the crack tip will be obtained initially. The figure also indicates the longitudinal grid which is milled on the entire upper specimen surface for direct measurement of the relative rotation of the two specimen halves using Moire interference pattern.

Table 1. Chemical composition.

Components (Wt%)						
C	Si	Mn	P	S	Al	Nb
0.14	0.30	1.41	0.014	0.011	0.045	0.030
V	N	Mo	Cu	Cr	Ni	
0.008	0.005	0.004	0.009	0.02	0.04	

The chemical composition forms the test protocol for the Mn-alloyed, normalized steel as shown in Table 1. The result from a static tensile test is shown in Fig. 4.

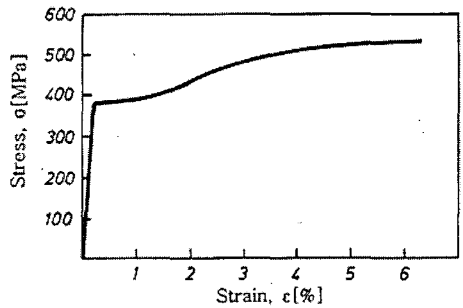

Fig. 4 Static tensile test diagram. (engineering strain and stress)

High speed photography is used for overall recording of the dynamic experiments and for detailed measurement of crack propagation and crack tip opening displacements (CTOD)[8]. The relative rotation is calculated from the distance between the Moire interference pattern lines as obtained the high-speed photos. A force transducer is incorporated in the mid-support, see Fig. 1. The time for impact is detected by the strain gauges attached at the specimen ends where the hammer hits the specimen. The camera was operated with 100,000 frames per second at the 30.2 m/s impact tests and with 160,000 frames per second at the 45.2 m/s tests. Moire interference pattern is obtained between the grid milled on the specimen surface and the reference grid which is kept at a distance of 3 mm above the specimen[9].

3. Experimental results

Results from three experiments on the new specimen design will be presented here : one "static" test(midpoint loading with as displacement rate of 50 mm/minute) and dynamic tests at the impact velocities 30.2 and 45.2 m/s. Possible influence of the loading rate can be displayed when the results are presented as a function of the relative rotation of the two specimen halves. Fig. 5 shows the crack propagation for the static and the two dynamic cases. The crack propagation corresponding to the blunting at the crack tip seen on the static experiment photos is included in this diagram.

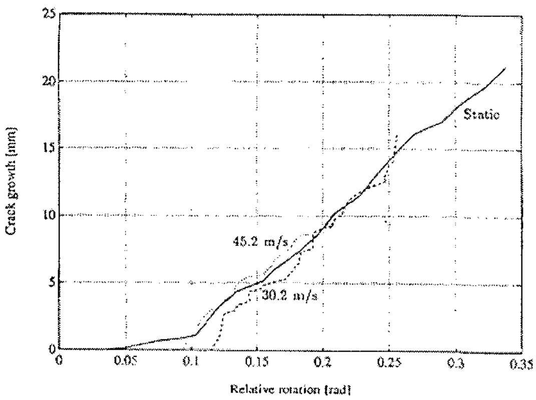

Fig. 5 Crack propagation for the static and the two dynamic cases as a function of the relative rotation.

The diagrams for the three loading cases are close to each other with a slightly earlier crack propagation for the 45.2 m/s case as compared to the static and the 30.2 m/s dynamic test. The Crack Tip Opening Displacement, CTOD, is presented as a function of the relative rotation in Fig. 6. The result indicates that there is no or only a minor influence of the loading rate on the crack propagation properties on the crack growth and crack tip opening displacement. The result from the static and two dynamic experiment also falls close each other in this case. The midsupport force as a function of relative rotation is presented in Fig. 7. Mid support force becomes largest at relative rotation of 0.1 rad for the static and one dynamic case.

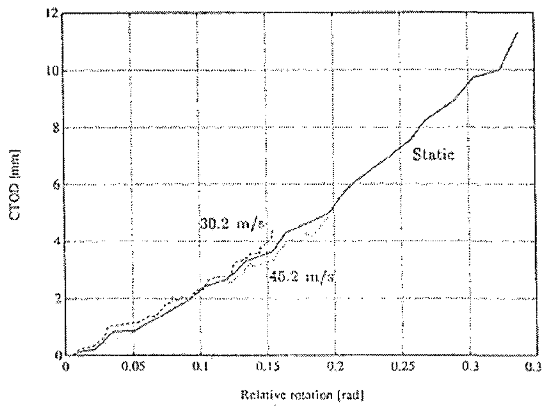

Fig. 6 Crack tip opening displacement for the static and the two dynamic cases as a function of the relative rotation.

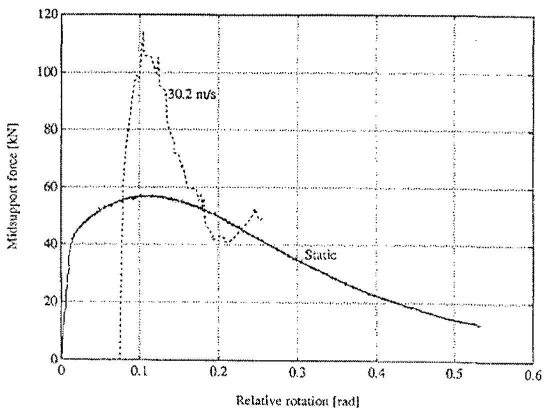

Fig. 7 Mid support force from the static and one dynamic case.

4. Conclusions

From the impact experiment for the nonlinear plastic behavior with the dynamically loaded 3PB specimens, the following results are obtained.

1. A slightly earlier crack propagation for the 45.2 m/s case is shown as compared to that of the static and the 30.2 m/s dynamic case.
2. There is no or only a minor influence of the loading rate on the crack growth and crack tip opening displacement as a function of relative rotation.
3. The Crack Tip Opening Displacement, CTOD can be presented as a function of the relative rotation.
4. Mid support force becomes largest at relative rotation of 0.1 rad for the static and one dynamic case.

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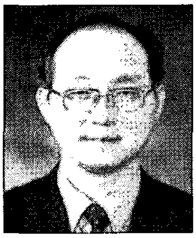

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<Research Interest>
Design of mechanical & automotive parts, Assessment of durability, Dynamic analysis at fatigue or impact