DETERMINATION OF CRACK-INITIATION TOUGHNESS BY IMPACT AND DYNAMIC TESTING

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The critical J-integral (J_{id})can be useful as toughness parameter at initiation of stable crack growth. Under the condition of the impact bending test the critical step for evaluating of J_{id} is the detection of the crack initiation point on the impact load displacement curve. In this paper the crack initiation is determined by using emission of acoustic waves (AE). The experimental techniques used to evaluate J_{id} include both instrumented impact testing based on 300 J pendulum impact tester with a piezoelectric broadband AE sensor within the impact tup and dynamic 3 point bending loading with a servohydraulic test machine and additional AE sensors on the specimen.

Different kind of pulses of the AE signals can be observed. One of them corresponds with crack initiation. The evidence of initiation at this point was confirmed by single and multiple specimen methods.

INTRODUCTION

It was found that the J-integral at crack initiation (J_{id}) is a material parameter which does not depend on the specimen geometry (1). A central and still unsolved problem is the detection of crack initiation in the load displacement curves obtained by impact testing. In this case the measurement of physical quantities connected with the process of stable crack initiation is necessary. There are only a few methods to detect the crack initiation under dynamic loading, as for instance the optical measurement of crack opening displacement (2) and acoustic emission (3-5). In this paper first experiments performed with a special instrumentation for the - simultaneous recording of impact force and emitted acoustic waves (AE) are presented.

The development of a method like this can be of interest for investigation and fracture mechanical characterization of irradiated reactor pressure vessel (RPV) steels because quantity and piece size are necessarily very limited.

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EXPERIMENTAL

The block diagram in Fig.1 shows an overview of the experimental arrangement. For the impact loading of the specimens a pendulum impact tester with a maximum initial energy of 300 J was modified. The pendulum is instrumented to measure the impact force according to recently recommended methods (6). In order to measure AE during loading a piezoelectric broadband AE sensor was designed and installed within a drilled hole of the impact tup. The distance between sensor and crack front is 29 mm at the beginning of loading. The impact tests were performed either at varying test temperatures with an initial loading velocity of 2.8 m/s or at room temperature with varying blow angles (low blow).
In order to avoid impact effects on the AE-signals a servohydraulic testing machine was used for loading the specimens with an initial loading velocity of 0.1 m/s. The specimens were loaded till controlled deflections. The used instrumented tup was as designed as for the impact tests. Additionally AE-sensors (dashed lines in Fig. 1) were mounted on the specimen surface.
A rolled bainitic-ferritic high strength steel with German designation 10CrMo9.10 with an upper shelf Charpy energy of approximately 250 J and a Charpy transition temperature (68 J criteria) of -45°C was investigated. Fatigue precracked Charpy V-notch T-L specimens with 20% side grooves were used to obtain impact and dynamic toughness properties.
For verifying the estimated crack initiation toughness crack extension curves and the stretch-zone width (SZW) were measured. A static J-R curve was obtained by means of the single specimen unloading compliance technique. Both dynamic multiple specimen methods (plastic range low blow and Cleavage R-Curve method) yield to dynamic J-R curves including the extrapolated crack initiation toughness.

RESULTS

A typical load curve of the impact test and the simultaneous AE obtained at room temperature and for an initial hammer velocity of 2,8 ms^{-1} are shown in Fig.2. From the load time curve three different phases can be recognized which are connected with typical acoustic features. Phase 1 is marked by strong oscillations of the load as well as of the AE signal. Small load oscillations and large plastic deformation characterize phase 2. It is accompanied by lower acoustic intensity. The characteristic of acoustic emission clearly differs from phase 1. The third phase begins with a load drop caused by the start of unstable crack growth. The sensitivity of the AE detector to detect acoustic events connected with unstable crack extension is evident from the strong AE intensity in this phase. Alternate periods of crack arrest and plastic deformation with repeating stable crack growth are also manifest in the rms-value (root mean square) of the AE-signal.

The initiation of stable crack growth cannot be identified from the load trace, but a special treatment of AE data renders it possible. Low blow tests with varying blow angle and the Cleavage R-Curve method were chosen to find the point of stable crack initiation. Both methods provide approximately the same initiation deflection d_i^* of 0.9 mm after extrapolation to zero crack growth. The time pertaining to initiation deflection $t(d_i^*)$ is marked in Fig. 2 and leads to J-integral $J_{id}(d_i^*)=170$ N/mm. This value corresponds with J_{id} computed from measurements of the SZW (180 N/mm) shown in the J-R-Curve in Fig. 3.

The following different AE types are observed near the initiation deflection d_i:

- Type A: caused from mechanical effects of the impact loading (phase 1)
- Type B: can be connected with the crack initiation and growth process (phase 1/2).

Signal type B usually occurs very close by the estimated crack initiation time $t(d_i^*)$. In agreement with results mentioned in references (3-5) the occurrence of signal type B seems to be associated with the beginning stable crack growth.

The impact of the tup superimposes the AE signals in phase 1 and at the beginning of phase 2 (Fig.2). This fact impairs the obvious interpretation of these signals. To avoid the impact effects specimens were loaded with a servohydraulic test system. A typical force time curve and AE signals measured with the different sensors (Fig.1) during the dynamic test are shown in Fig. 4. There are no oscillations in the load trace during the dynamic loading without impact. The records of AE signals are preferentially concentrated into two clusters. The first cluster is certainly caused by plastic yielding. This kind of AE signal wears off till the onset of the next AE signal. The second AE signal cluster has burst character and occurs between yielding and maximum load. The symmetrically to the crack arranged sensors SE 2 and SE 5 (Fig. 1) receive the signal simultaneously. Thus, the signal source is localized in or near the crack plane in the specimen middle. The AE sensor placed within the tup records this AE burst with weak sensitivity in consequence of interfaces, wave mode conversion and attenuation of the emitted acoustic waves. If J_{id} is calculated at this time point the value coincides the fracture toughness value J_{id} in accordance with the results of the crack resistance curve of Fig. 3. That is a supportive hint that the second signal cluster reveals crack initiation.

CONCLUSIONS

AE during dynamic fracture toughness tests of a heat resistant steel was investigated by an AE analysis in combination with multiple specimen techniques. Different behaviour of the measured AE was observed in impact and dynamic tests. The results are summarized as follows:

1. Both impact test and dynamic loading provide AE signals which are caused by ductile crack initiation.
2. The J_{id} values determined by using AE signals are comparable with J_{id} values ascertained with multiple specimen methods and SZW measurements.
3. The AE sensor placed within the tup records AE burst with the weak sensitivity in comparison with sensors mounted on the specimen. The spectral and absolute sensitivity of this sensor have to be improved. This will be realized in the next time.
4. A further step has to examine the AE technique for testing of steels with lower ductility.

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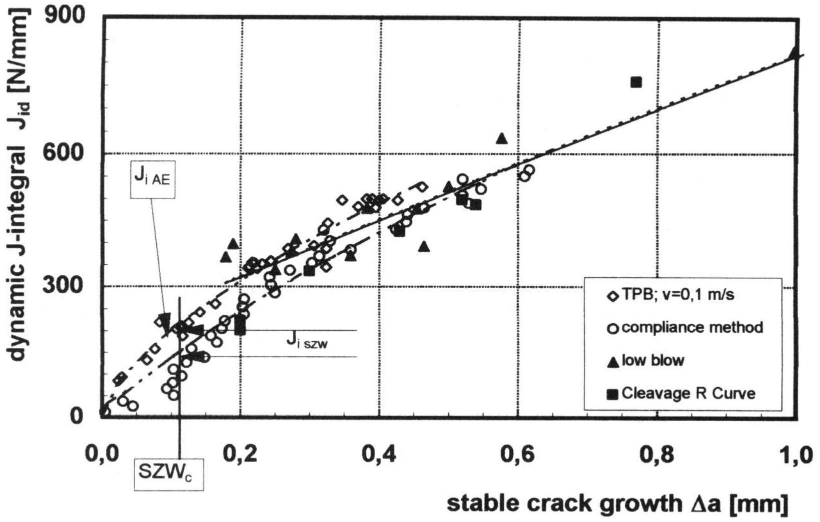

Fig. 3: J-R-Curves and crack initiation toughness obtained with various methods on one material

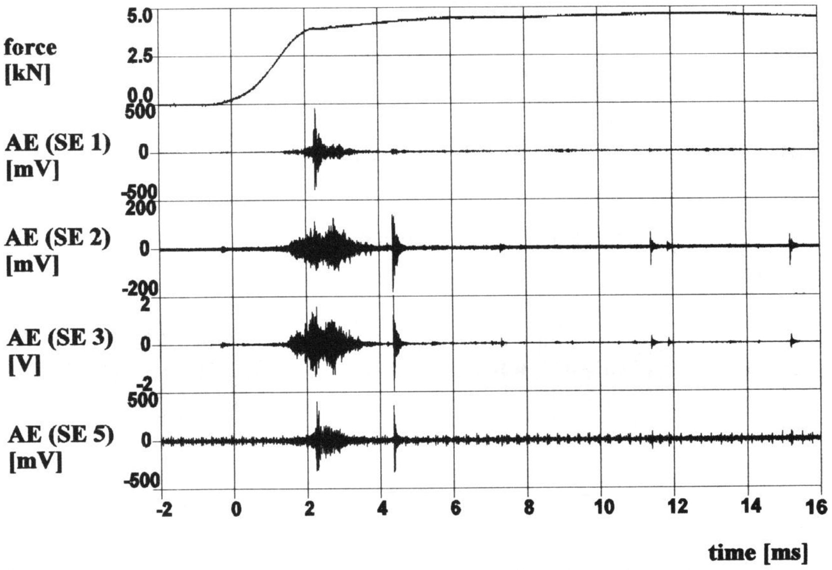

Fig. 4: Typical load curve and AE signals during dynamic test (v = 0,1 m/s, room temperature)

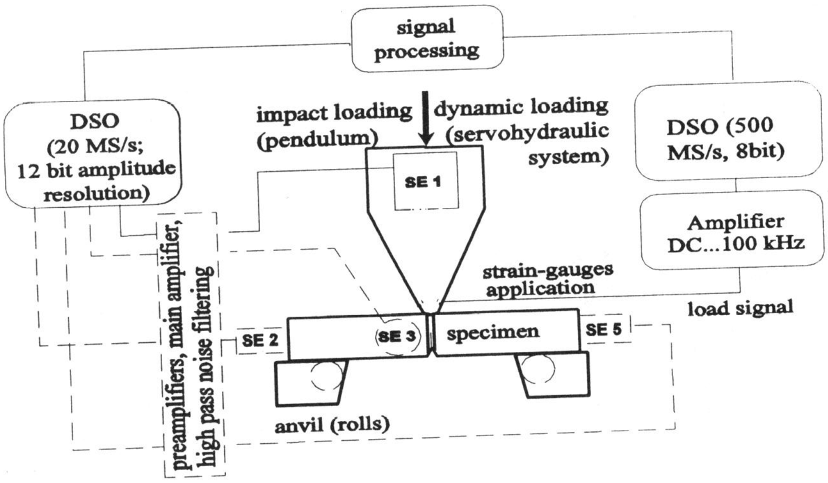

Fig. 1: Experimental setup for impact testing and additional AE-instrumentation (dashed lines) for dynamic testing

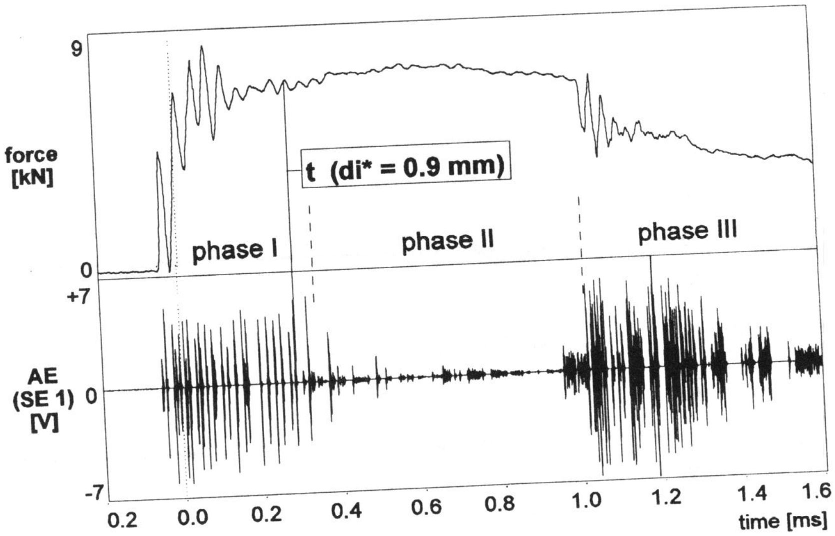

Fig. 2 : Typical load and additional AE curves at impact loading