On the Applicability of Magnetic Emission Measurement Technique for Dynamic Fracture Toughness Determination of Large Specimens

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ABSTRACT: *The aim of the present work was to apply the magnetic emission technique in instrumented drop weight testing of large SE(B) fracture mechanics samples. Cast ferritic steel specimens have been tested in the lower shelf region. Two evaluation methods have been used and compared: force based quasi-static evaluation and dynamic key curve method. For the latter one the time-to-fracture measurement is necessary, which was done by applying the magnetic emission measurement technique. The magnetic emission probe was successfully installed onto a drop weight tower first time in the world. The two evaluation methods delivered very similar* K_{Id} *values.*

INTRODUCTION

The instrumented impact testing technique is widely used for determining dynamic fracture toughness properties of small Charpy type specimens. But this specimen size usually does not deliver valid fracture toughness data. For larger specimens the instrumented drop weight testing is an applicable experimental technique.

Due to dynamic effects for higher impact velocities several special problems are encountered. Therefore, the application of conventional force based analyses is limited up to a certain loading rate, especially in the lower shelf region when brittle fracture can occur after a few hundred microseconds. Over this range, the dynamic effects very often overshadow the true material response and additional measurement techniques must be applied to determine dynamic fracture toughness. The magnetic emission technique (ME) has potential ability for detecting the crack initiation, therefore the real time-to-fracture can be determined for dynamic analyses [1,2, 3].

The main aim of our work was to determine the dynamic fracture toughness values of large SE(B) specimens of cast ferritic steel, and to compare two evaluation methods: the quasi-static force-based evaluation and the dynamic key curve method.

IMPLEMENTATION OF THE MAGNETIC EMISSION MEASUREMENT TECHNIQUE FOR DROP WEIGHT TESTING

The magnetic emission probe was successfully installed onto a drop weight tower of 550 J maximum available energy. Figure 1 shows the testing machine with the magnetic probe. The position of the probe can be adjusted in order to position it 2-3 mm far from the specimen side, and near to the crack tip. The probe was fixed to the moving weight, so it can follow the movement of the specimen and it is always near to the crack tip until the crack propagation does not start.

The impact velocity can be varied with changing the drop height, and the impact velocity is measured with an optical trigger device fixed onto the frame of the machine. This device makes the data acquisition start. A two pins flag is fixed on the falling weight which goes through the optical device, two pulses are produced and the time interval between these pulses is measured by a clock, and from this time value the impact velocity can be determined. The strain gauges of the tup and the emission probe are connected to a voltage supplies and amplifiers, and their signals are recorded by a TEKTRONIX TDS 420A digital oscilloscope. Then after transferring the data to a PC the evaluation is usually done with spreadsheet procedure.

EXPERIMENTS AND RESULTS

The tested material was cast ferritic steel which can be used for production of spent nuclear fuel containers. Two series of large SE(B) specimens were tested: series E was cut from near surface of a thick cast plate, and series C – from the centre part. The specimen dimensions were 23x23x110 mm which was selected taking into account the width of the instrumented tup. Two impact velocities were applied - v_o= 1.94 and 2.94 m/s – in order to eliminate the strong dynamic effects. Some preliminary experiments were performed to find the lower shelf region for the two sets of specimens. The test temperature was finally varied in the range from -60 to -20 °C in order to obtain brittle fracture initiation.

a)

b)

Figure 1: The instrumented drop weight tower (a) and the instrumented tup with the magnetic emission probe (b)

In the *lower shelf region* brittle crack initiation occurred preceding by no any macroscopic plastic deformation (Figure 2.). For the higher impact velocity the dynamic effects were more pronounced, and the „3τ" criteria [4] was usually not fulfilled.

But nevertheless, the quasi-static evaluation method was tried to be applied. For this, the force based analyses was used, and the K_{Id} was determined according to standard procedure described in [5].

When the dynamic effects are too strong the force based analyses usually can not be applied. For these cases Böhme developed the dynamic key curve (DKC) method [6]. According to this method the dynamic fracture toughness can be determined on the basis of the measured time-to-fracture value with eq. 1:

$$K_{Id} = \frac{E.Y\left(a_0/W\right)}{\sqrt{W}\,C_s^*\left(1+C_m/C_s\right)} \mathrm{v}_0 t_F k_{dyn}(t=t_F) \tag{1}$$

where E - specimen's Young modulus , MPa

v_o - impact velocity, m/s

$k_{dyn}(t_F)$ - dynamic key curve

t_F - time-to-fracture, s

C_s - specimen compliance, m/N

C_m - machine compliance, m/N

$C_s^*=EBC_s$ - dimensionless specimen compliance [7]:

$$C_S^*\left(a_0/W\right) = 20.1+135\left(a_0/W\right)^2 \begin{Bmatrix} 1-2.11\left(a_0/W\right)+8.76\left(a_0/W\right)^2-19.9\left(a_0/W\right)^3+41.4\left(a_0/W\right)^4 \\ -67.7\left(a_0/W\right)^5+92.1\left(a_0/W\right)^6-76.7\left(a_0/W\right)^7+35.6\left(a_0/W\right)^8 \end{Bmatrix} \tag{2}$$

$Y(a_o/W)$ - geometry function for SE(B) specimen [5].

According to the DKC method, the value of k_{dyn} depends on the W/c_1 ratio, where c_1 is the longitudinal wave propagation velocity for plane strain:

$$c_1 = \sqrt{\frac{E}{\rho\left(1-\nu^2\right)}} \ . \tag{3}$$

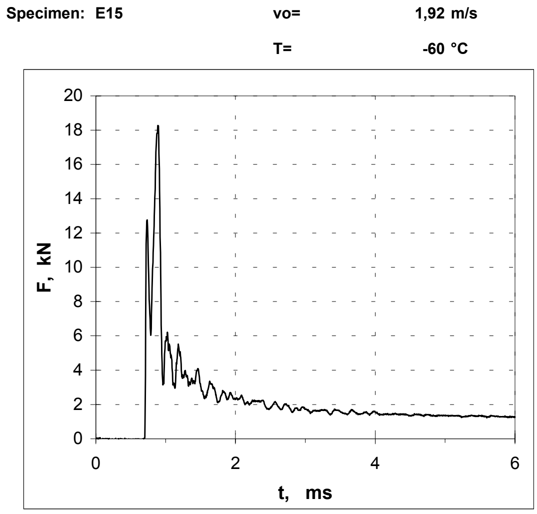

Figure 2: Typical force time curve of cast ferritic steel in the lower shelf region

When t_f<39.4W/c_1 - for a_o/W=0.5 - (168 μs in our case) we are in the fully dynamic time range. In this time range, the crack tip loading is significantly affected by dynamic effects. In the intermediate time range – if 39.4 W/c_1<t_f< 80.9 W/c_1 (between 168 and 345.2 μs) – the dynamic key curve value is k_{dyn}=1. In this range the dynamic effects have decreased significantly, but the externally measured loads are still influenced by them. Above this, the loading rate can be considered as quasi-static. Almost all of the experiments were within the intermediate range

The time-to-fracture determination was based on the force and on the magnetic emission signals. Unstable crack propagation is indicated by a force drop and usually is accompanied by a sharp peak of the magnetic signal according to a rapid crack jump. But due to the strong oscillation of the force signals, it was sometimes difficult to determine the instant of the brittle fracture directly from the force-time curves. Figure 3 shows one example for the time-to-fracture determination.

The experimental results for the two experimental series are summarised in Figure 4 and Figure5. The transition region was a little bit lower for series E, therefore the temperature region of the experiments was also lower.

It can be seen from theses figures that the two evaluation methods (quasi-static and DKC) delivered very similar results. For series C, the exponential fit gave practically the same curve, and for the series E the DKC method delivered a little bit lower K_{Id} values (with app. 5 MPa√m).

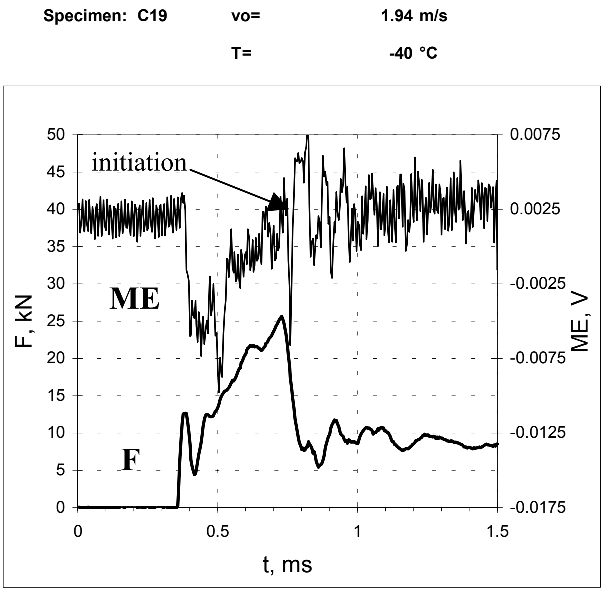

Figure 3: Time-to-fracture determination using magnetic emission signal

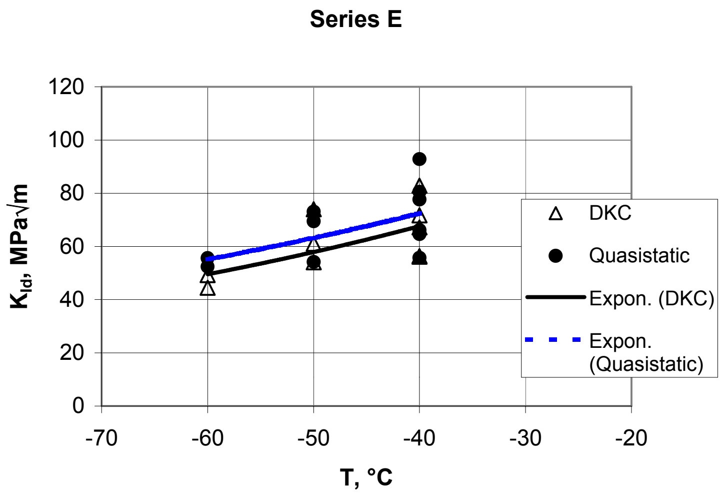

Figure 4: Dynamic fracture toughness vs. temperature for series E in the lower shelf region

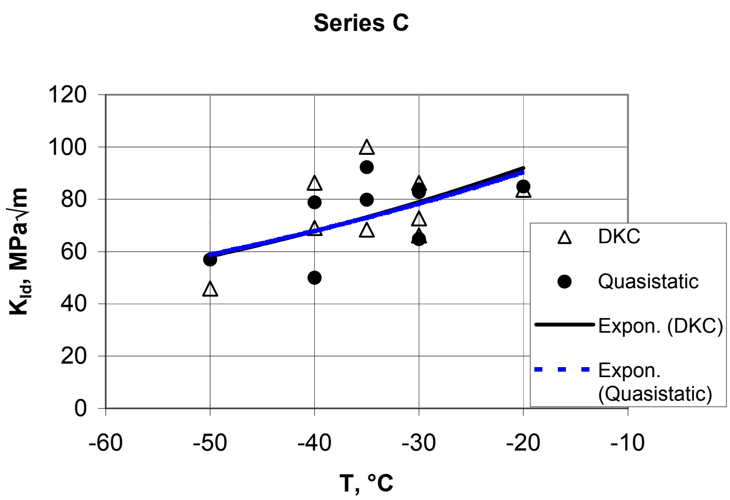

Figure 5: Dynamic fracture toughness vs. temperature for series C in the lower shelf region

SUMMARY AND CONCLUSIONS

Two specimen series of cast ferritic steel were investigated experimentally to determine the temperature dependence of the dynamic fracture toughness. Large SE(B) specimens have been tested with instrumented drop weight testing. Two different evaluation methods were used: the force-based quasi-static evaluation and the dynamic key curve (DKC) method. For the DKC method the time-to-fracture values were determined using the magnetic emission measurement technique.

On the basis of the obtained results the following can be concluded:

1. The magnetic emission probe was installed onto the drop weight tower, and was successfully applied for time-to-fracture determination.
2. The specimens cut from the surface part of a thick cast plate (series E) had a higher transition temperature than of the specimens which were originated from the centre part (series C) of the plate.
3. The two different evaluation methods delivered approximately the same dynamic fracture toughness values as average.

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