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ON THE DYNAMIC FRACTURE TOUGHNESS DETERMINATION BY INSTRUMENTED IMPACT TESTS

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INTRODUCTION

The instrumented impact tests have become a more and more widely used method for dynamic fracture toughness determination [1 - 6]. This test combines the conventional impact tests with the simultaneous measuring and recording of the bending load and the specimen deflection (or the speed of the deflection) by means of high-speed low-inertial electronic system, which include usually strain gauge transducer installed in the impact machine tup for load measurement, photoelectronic system for the deflection measurement and a storage oscilloscope for display and recording. The oscillograms obtained during the impact tests represent load-deflection or load-time and deflection-time curves. This qualitative new information, which could not be obtained from the conventional impact tests provides the possibility of dynamic fracture toughness determination.

But there are at least two basic difficulties in the application of instrumented impact tests to these purposes: First of all, in many cases it is quite difficult to achieve a plane-strain condition in so small a sample as Charpy specimen, even precracked. Some measures like machining of the side grooves suppress to some degree plastic deformation and shear lips formation, thus approaching to plane-strain state. But until now it is not clear to what degree these measures improve the situation and make the obtained data reasonably valid. Secondly, in cases when the fracture occurs without appreciable macroscopic plastic deformation and the plane-strain condition is believed to exist the oscillations depicted on the elastic part of the loading-time curve make the interpretations of the oscillograms quite difficult.

Physical nature of the first oscillations on the load-time curves and factors influencing their formation were under extensive investigation in the recent decade [7 - 12]. In spite of the significant progress in the understanding of the relevant role of the recording system parameters [10], acoustic properties of the specimen and inertial effects [4, 12] in the formation of the loading-time curves, there still exists the need to develop an adequate model of the impact test for more reliable estimations of the bending force and moment, thus providing the basis for dynamic fracture toughness evaluation.

The model proposed in the present paper is based on the theory of the beam's vibration and a sufficiently good correlation between the calculated and experimental values make this approach quite promising.

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BASIC ASSUMPTIONS AND MODEL

We introduce the general idea, using the simple model of impact loading of the Charpy-type specimen as a three-point bending beam.

The following set of assumptions is introduced:

1. The specimen is considered as a beam with two hinged bearing edges loaded in the middle of the span by the impact load P(t);
2. Only the elastic part of the loading process is considered;
3. The cross-section of the beam is rectangular and constant along the beam length.

Further, in what follows, we follow the Timoshenko approach [13], based on displacement balance.

According to [13] the hammer displacement during impact must be equal to the sum of the beam deflection and the contact displacement of two contacting surfaces (hammer tup surface and specimen surface in load-point). Considering the contact displacement in the framework of the contact problem (neglecting dynamic effects) and the beam deflection in the framework of the theory of the beam vibration Timoshenko obtained the following integral equation for the bending load P(t)

$$V_o t - \int_0^t dt_1/M_o \int_0^{t_1} P(\tau)d\tau = ZP^{2/3}(t) + \sum_{n=1,3,...}^{\infty} \frac{2gL}{n^2\Pi^2 CS\mu} \int_0^t P(\tau)\ \mathrm{Sin}\ \frac{n^2\Pi^2 C(t-\tau)}{L^2}\ d\tau \qquad (1)$$

Where V_o - initial speed of the hammer, t-time, M_o - mass of the hammer, Z - the compliance constant depending on elastic properties and geometry of the contacting bodies, g - acceleration of gravity, L - the beam span, S - the beam cross-section area, μ - specific weight of the beam material, $C = EIg/S\mu$, E - Young's modulus and I - moment of inertia.

The expression on the left of the equation (1) represents the hammer displacement, the first term in the right part represents the contact displacement and the last term - the dynamic deflection of the beam.

When P(t) is found from (1) the moment for the middle span cross-section can be obtained as follows [13]:

$$M(t) = -EI\frac{d^2y}{d\chi^2} \qquad (2)$$

Where M(t) the bending moment in the middle span cross-section, y - the dynamic deflection of the beam and χ - coordinate axis along the beam.

CALCULATIONS AND RESULTS

Expression (1) and (2) were used for calculation of bending force P(t) and bending moment in the middle span cross-section M(t) as a function of the time. The calculations were performed on an IBM computer. The

following data simulating the Charpy test of the steel specimens was used: Young modulus $E = 2 \times 10^4$ Kg/mm^2. Poisson ratio $\nu = 0.3$, the beam span L = 40 mm, the beam width B = 10 mm, the beam height H = 8 and 10 mm, initial hammer speed V_o = 5.5 m/sec (which corresponds to the hammer speed of existing impact machine used for instrumented impact tests). In order to estimate the influence of the contact conditions on the hammer tup-specimen interface the calculations were performed for the variety of values of the compliance constant Z.

On Figure 2 as an example of the calculation results two calculated load-time curves are shown: The dashed line represents the 10 x 10 cross-section specimen (corresponds to the gross cross-section of the Charpy specimen) and the dot-dash line represents the 8 mm height specimen (corresponds to net cross-section of the Charpy specimen). Both calculations were made using the same value of the compliance constant ($Z = 0.6708.10^{-4.66}$ cm. $N^{-2/3}$). The solid line in Figure 2 represents the experimental load-time curve obtained during instrumented impact test of almost entirely brittle steel. As can be seen from Figure 2 the experimental curve coincides almost over the whole time range with the calculated curve for the 8 mm height specimen. The deviation begins only when the maximum tensile stresses calculated for 8 mm height specimen become greater than the yield strength of the material.

Since the difference between the yield point and the ultimate strength in this material is low the load-time curve deviation from the calculated values can reflect both the yielding phenomena and the initial stage of the crack propagation. Comparison of the calculated and experimental curves shows that the model based on the net cross-section corresponds more satisfactory to the experimental data thus demonstrating the influence of the specimen notch on its rigidity.

A good similarity between the calculated and experimental curves (elastic part) was found for the variety of specimen cross-section dimensions.

It must be noted that the calculated values of the middle span moment are not subjected to any appreciable oscillations in spite of significant oscillations of the bending force (see Figure 2). This fact is also in a good accordance with the experimental data [9], (see Figure 1).

The results of this investigation show that: (a) the relation between contact compliance of the hammer tup-specimen system and the dynamic compliance of the specimen as a vibrating beam greatly influence the formation and intensity of the first oscillations on the load-time curves obtained during instrumented impact tests, (b) these oscillations reflect the load acting on the hammer tup-specimen contact area, (c) there is no simple correlation between the load recorded during instrumented impact test and the middle span moment, (d) this moment can be determined by means of the calculation procedure proposed here, (e) load-time oscillograms obtained during instrumented impact tests may be used as initial data for the moment, stresses and dynamic fracture toughness calculation.

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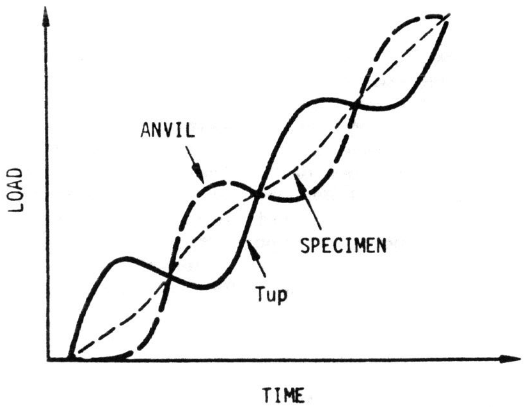

Figure 1 Relationship of Specimen, Hammer Tup and Anvil Reactions During Impact [9, 10]

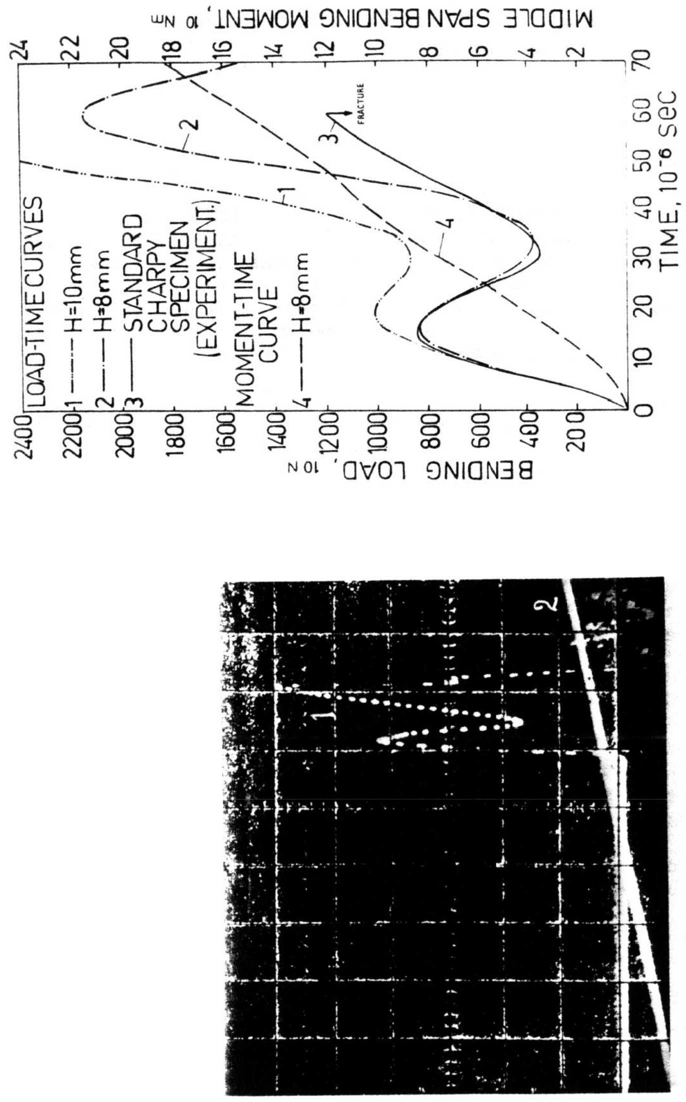

Figure 2 Dependance of the Bending Force and Middle Span Moment on Time

(a) Oscillogram of the Instrumented Test of Charpy Specimen; (1) Load-Time Curve; (2) Deflection Time Curve. Vertical Axis-One Division 2kN; Horizontal Axis-One Division $50x10^{-6}$ sec.
(b) Calculated and Experimental Curves. Curve 3 Corresponds to the Oscillogram on Figure 2a