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EXPERIMENTAL INVESTIGATION OF THE INERTIAL EFFECTS OCCURRING IN IMPACT TESTS ON PLASTICS WITH VARYING MASS DISTRIBUTION

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ABSTRACT

Aim of the work is to elucidate some aspects of the phenomenology of impact tests in order to improve previously proposed modelizations. The experimental investigation focused on the influence of specimen dimensions and specimen mass distribution on the inertial effects observed in the initial part of an impact test. The experiments were carried out on single-edge notched specimens in the "one-point bending" mode. The flexural compliance of the notched specimens was varied by varying notch depth and specimen length and their mass distribution was varied by varying their length and by adding some concentrated masses. Analysis of the load-time traces recorded by the instrumented tup of the striker impacting the specimen at 1 m/s shows the distinct role played by the "contact mass" involved in the very first instants of the impact process, and by the inertia of the specimen wings. The "dynamic" one-point bend compliance of the specimen appears to be proportional to its "static" three-point bend compliance, if the specimen length in the former bending mode is equated to the span between the anvils in the latter bending mode. These results gave hints to the improvement of a previously proposed 'analogical' model for simulating the dynamics of the impact test.

KEYWORDS

Instrumented impact test, One-point bending, Inertial effects, Impact fracture, High rate of loading

INTRODUCTION

Use of instrumented impact testers is becoming commonplace and acquisition of the load vs. time response from a pre-cracked specimen makes the test amenable to fracture mechanics analysis, thus allowing an (intrinsic) value of fracture toughness to be extracted from the experimental data.

The analysis of the force-time trace recorded in an impact test, however, is complicated by the dynamic effects occurring when the test piece is loaded rapidly. Even at moderately high loading rates (speeds of the order of 1 m/s) the inertial forces set up by the accelerating masses produce effects that may mask the true response of the material. These effects are reflected in the recorded force signal and need to be recognized and properly accounted for if the true impact resistance of the material itself is to be extracted from the experimental data.

In a previous work [1] we have demonstrated the usefulness of one-point bending impact experiments (same configuration as in a three-point bending test but without anvils) to elucidate the dynamics of the specimen deformation. Aim of the present work is to extend the investigation to non-standard specimen dimensions in order to elucidate the effects of varying the distribution of the masses involved in the impact process.

EXPERIMENTAL DETAILS

Impact tests were performed with an instrumented pendulum (Resil 25 by CEAST, Turin) in the Charpy configuration but with the two anvils removed (one-point bending mode). Built-in instrumentation consists of a strain-gauge load cell mounted in the tup of the striker to measure the force acting on its nose and a data acquisition system capable of capturing the force signal every 1 μs. A test speed (load-point displacement rate) of 1 m/s was applied and the impact energies used were far in excess of the energy subtracted by the specimen during the test, so that variations in the striker speed during the test were negligible. Standard (according to 2,3) and non-standard single-edge-notched (SE(B)) specimens of a rigid polyvinylchloride (PVC), were used. The specimen cross-section measured 8.1 mm in thickness (*B*) and 16.2 mm in width (*W*), while specimen length (*L*) and notch depth (*a*) were varied over wide ranges. The specimens were carefully machined to provide the best possible tup/specimen contact at impact so as to obtain reproducible measurements. An example of the degree of reproducibility generally obtained in this work is shown in Figure 1.

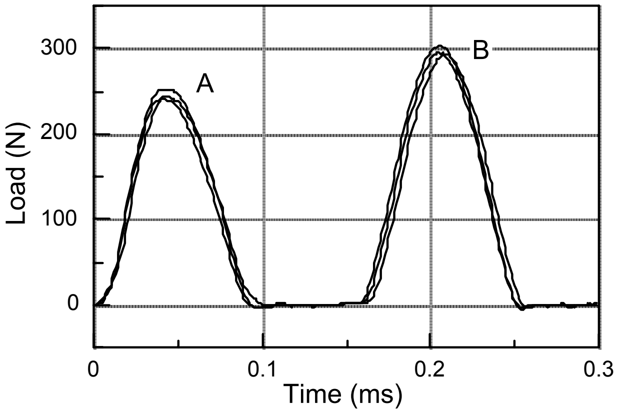

Figure 1 - Examples of load-time trace reproducibility: three replicates obtained from specimens with $L/W = 4.4$, $a/W = 0.5$.

To assess the effect of altering the mass distribution in the specimens, concentrated masses (lead tabs weighing 7.2 g each) were firmly glued either at the two ends of the specimens or at the two sides of the notch on the surface opposite to the impact point, as shown in Figure 2.

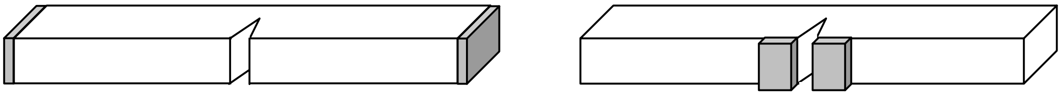

Figure 2 - Positions of added concentrated masses.

RESULTS AND DISCUSSION

Previous works [4,5,1] had already shown that the result of one-point bending impact tests is a series of peaks in the recorded force signal. We shall consider the first peak (often denoted as "*the* inertia peak") first and the subsequent peaks later on.

First peak

Previous observations [4,5,1] on specimens of standard dimensions ($W = 2B$, $L/W \approx 4$) but varying relative notch depth (a/W) had shown that the first peak recorded in the tests carried out at 1 m/s, with or without anvils, is nearly symmetrical (see e.g. in Figure 1) and invariant with a/W [5,1]. Since the notch depth affects the (static) flexural compliance of the specimen considerably, the latter observation suggested that the tup/specimen interaction reflected in the first peak involves only a limited portion of the specimen mass (the "contact mass"). By modelling the first tup/specimen contact as a simple mass-spring model ("contact mass" plus "contact stiffness") it appeared that the volume of the contact mass is constant (about 1.8 cm^3) for a wide range of test materials, specimen dimensions, test speeds and striker tup materials and geometries [6].

Results obtained with specimens of relative length L/W greater than the standard value of nearly 4 now show that only the ascending part of the peak is invariant with specimen geometry (Figure 3): the shape and the duration of the descending part is affected by a change in a/W and L/W.

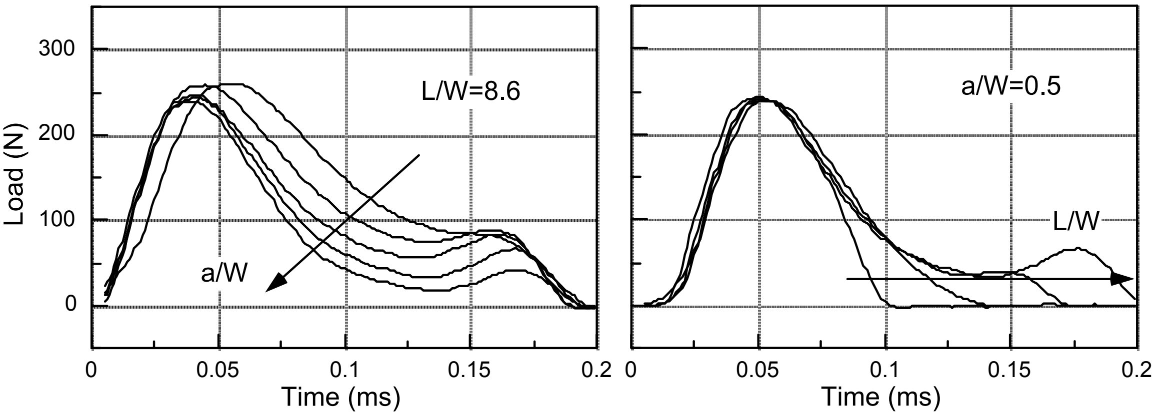

Figure 3 – Records of first peak obtained on specimens of relative length $L/W = 8.6$ and relative notch depth $a/W = 0.15, 0.3, 0.4, 0.5, 0.6$ (left) and specimens of relative notch depth $a/W = 0.5$ and varying relative length $L/W = 4.4, 6.1, 7.5, 8.6$ (right).

These results can be interpreted as follows. The ascending part of the peak reflects the acceleration of the contact mass, which is a limited portion of the specimen mass around the impact point. The remainder of the specimen is still at rest during this first stage: neither variation in length (L) nor in flexural compliance (through a/W) alter the specimen response to impact during this first stage. At the apex of the peak the speed of the contact mass reaches the speed of the striker and the force exerted on the tup (and sensed by the load cell) stops increasing. Afterwards, the speed of the contact mass keeps increasing [7] thus releasing the compressive force exerted on the tup (descending part of the force peak) until it reaches nearly twice a speed of the striker speed, as it can be predicted by an elastic analysis of a two-body impact. At this point the force acting on the tup of the striker vanishes, possibly reflecting loss of contact between tup and specimen.

During this stage of the impact process (descending part of the force peak) the reaction of the specimen to its bending starts to become appreciable, as indicated by the influence of the notch depth on the recorded load trace (Figure 3a): the greater the flexural compliance (as reflected in a/W) the shorter the duration of this stage. Consistently, also the wings of the specimen start moving, as indicated by the influence of the specimen length on the recorded load trace (Figure 3b): the greater the specimen length, the greater the inertia of the wings, the longer the duration of this stage.

This interpretation is supported by observations drawn from the experiments performed on specimens bearing added concentrated masses. Placing the weights at the center of the test bar produces the same effect as increasing the contact mass: both the intensity and the duration of the force pulse increase, as predicted by elementary mechanics (Figure 4, left). Placing the weights at the extremities of the test bar increases the inertia of the wings just as by increasing the specimen length, and the effect is an extension of the descending part of the force peak (Figure 4, right).

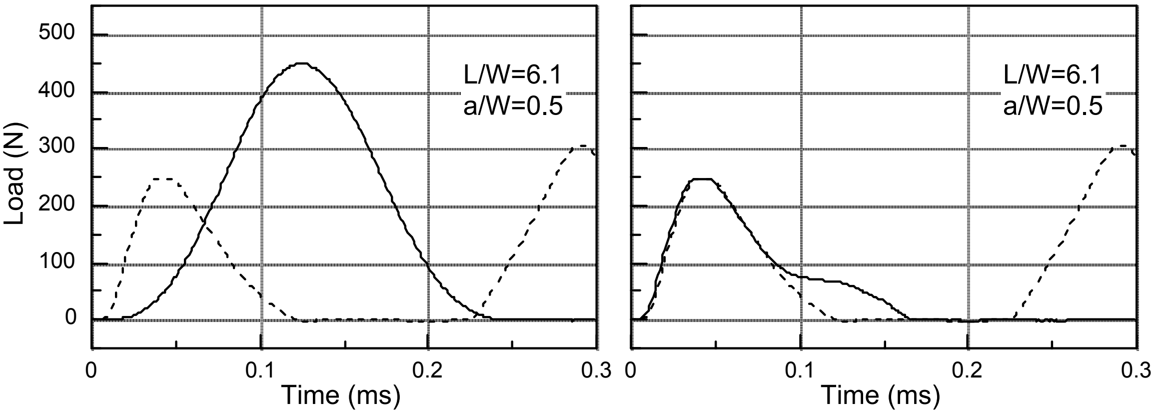

Figure 4 – Comparison of first peak records obtained from specimens of identical dimensions but with added concentrated masses placed either at mid-span (full line, left) or at specimen ends (full line, right). Dotted line: un-ballasted specimen.

Subsequent peaks

It was shown previously [5,1] that number and separation of the subsequent peaks change by varying the notch depth *a*, and the time interval between two consecutive peaks turned out to be proportional to the square root of the "static" bending compliance in three-point bending, at least for specimens of "standard" three-point bend dimensions ($S/W = 4$ and $L \approx S$) [1].

The investigation has now been extended to consider the effect of increasing the specimen length and adding some concentrated masses. An example of the results so obtained is shown in Figure 5. Number, shape and separation of the force peaks are all affected. In an attempt to rationalize the dependence of the separation between the main peaks on specimen length, we have plotted the time interval between the first two main peaks A and B, T_{AB}, (assuming it is proportional to the fundamental vibrational period of the beam) as a function of the square root of the dimensionless "static" bending compliance in three-point bending, $\psi(a/W, L/W)$ calculated from [8,9] according to [2] with $S = L$ (Fig. 6). The diagram collects all data points measured in the present work, with a/W ranging from 0.15 to 0.75 and L/W ranging from 4.4 to 8.6. The points appear to fall nicely on a single straight line through the origin. This finding confirms (as to the a/W-dependence) and extends (as to the L/W-dependence) the validity of the argument set out in [1]: the "dynamic" one-point bend compliance is proportional to the "static" three-point bend compliance, as specimen wings inertia acts like a constraint on the wings movement just as the anvils do in the three-point testing mode.

This result further strengthens the data interpretation given in [1]: the series of force peaks observed during the test reflects successive impacts of the striker tup onto the specimen, resulting from flexural vibrations of the moving specimen.

A similar analysis of the minor peaks appearing in the force-time records, including the one arising in the descending part of the first peak (see Figures 3 and 5) when specimen length, L, is increased, shows that they can be interpreted as the effect of higher modes of vibration. As a matter of fact their distance from the major peaks turns out to be in a constant ratio to the fundamental vibrational period (T_{AB}).

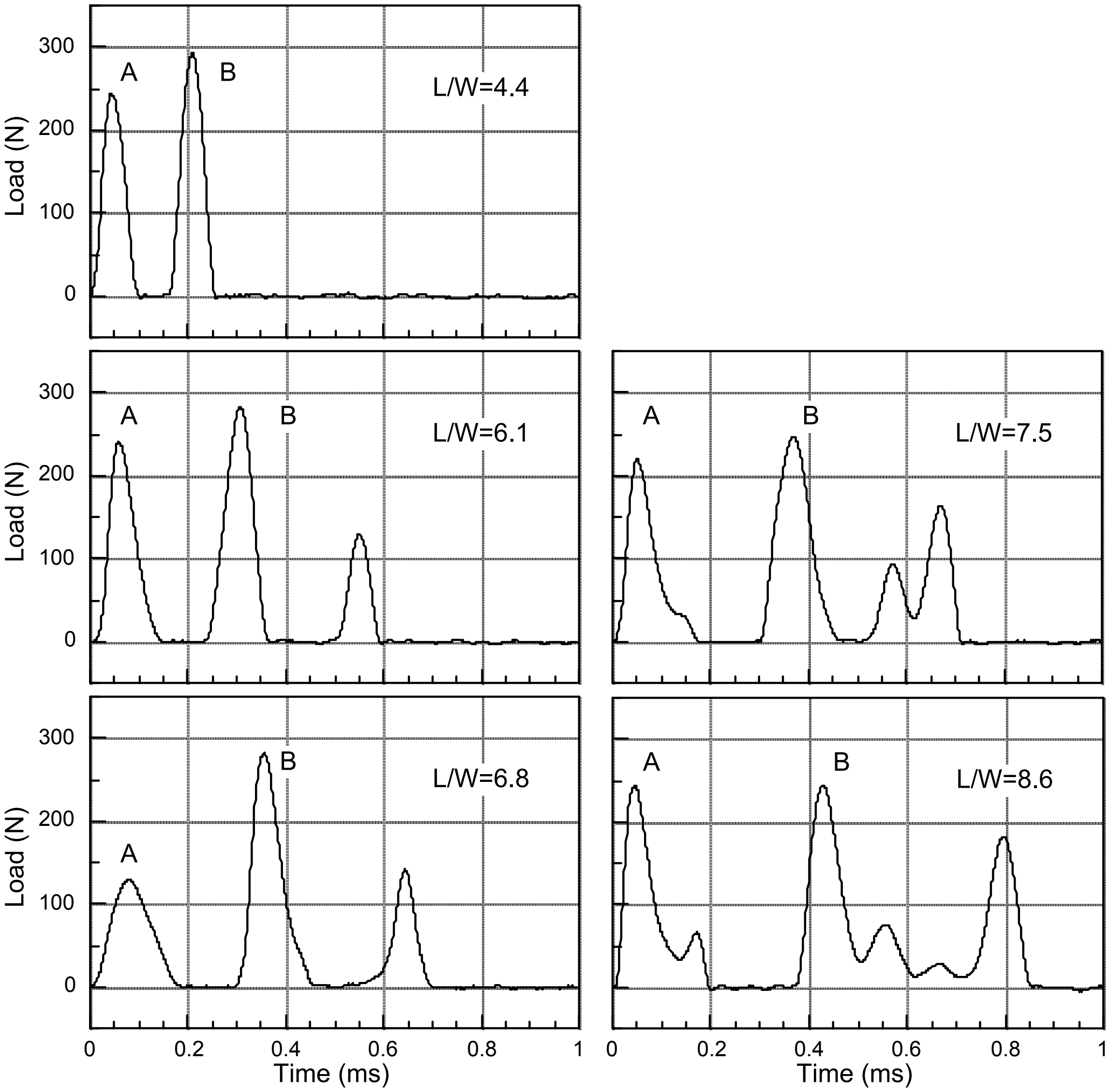

Figure 5 – Example of a load-time traces recorded in one-point bending impact tests on specimens with a/W=0.5 and varying relative specimen length L/W

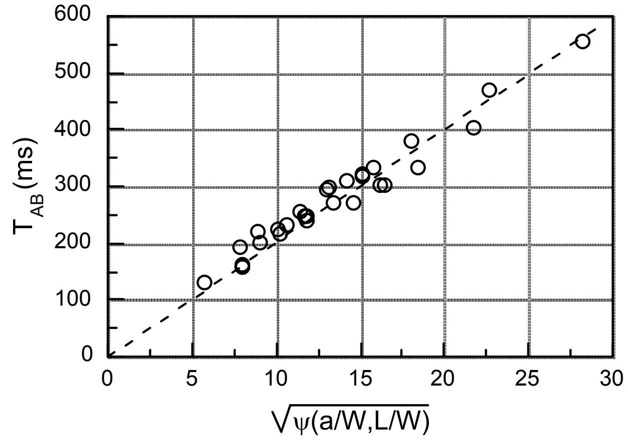

Fig. 6 – Time interval between the first two main peaks A and B of load-time traces recorded on specimens of varying relative notch depth a/W and relative length L/W, as a function

of the (dimensionless) three-point bending compliance $\psi(a/W, L/W)$

Modelization

In order to take into account the influence of specimen mass distribution and its variation with varying specimen length, a refinement of the model proposed in [1] was worked out [10]. Use of this model to extract the moment acting at the crack tip from the records of the apparent load measured at the striker tup is very promising. An example of its capability to simulate the test and reproduce the experimental load-time traces is shown in Fig.7.

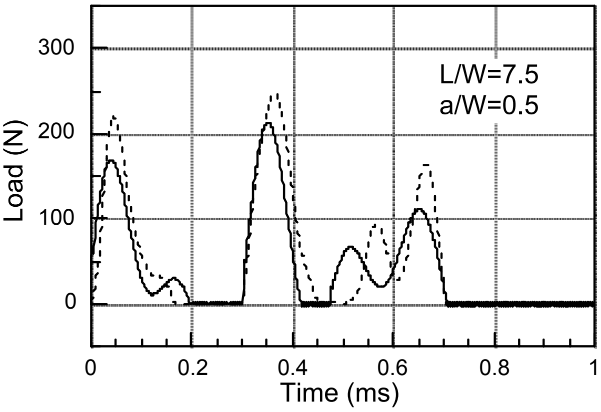

Figure 7 – Comparison of experimental (dotted line) and calculated (full line) load-time trace obtained from a one-point bending impact test on a specimen with *a*/*W*=0.5 and *L*/*W*=7.5.

CONCLUSIONS

The analysis of the force-time traces recorded in one-point bending impact tests performed on single-edge notched specimens of varying geometry and mass distribution allowed us to identify the origin of several features of the impact process. Based on these observations a further refinement of existing models for the test simulation was worked out, so that the model can be used to extract dynamic fracture toughness values from the impact test.

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