Dynamic Toughness Measurements by Instrumented Drop Weight Impact Tests

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Introduction. A picture of the effect of strain rate, $\dot{\varepsilon}$, on the fracture toughness, K_{1c}, of mild steel was proposed (1) with a high static toughness falling to a trough of low dynamic toughness, K_{1D}, at impact rate, and rising to greater toughness at very high rates. The initial high toughness barrier was less marked at low temperature. This simple picture is consistent with the well-known risks of brittle fracture in mild steel. Subsequent advances throw doubt on this model but the evidence appears conflicting, and the problem of measuring, interpreting and using dynamic toughness values remains unsolved. Some test evidence from static and impact tests, (2), and DCB tests (3) is consistent with the model of Ref.1, but not conclusive. Tests on thick pieces at intermediate strain rates show little effects, (4). Some steels show differing patterns of effects (5), whilst (6) proposes a fine spectrum of rate effects, apparently with little overall trend. On grounds that are by no means secure, the authors incline to an extension of Irwin's view that (static) toughness must for engineering purposes be represented by one parameter, and thus accept two, one static, one impact, as characteristic rate sensitive steels, even if more refined testing shows a more complicated pattern. Previously reported instrumented Charpy type tests (7) help the understanding of the mechanics of notch-bar impact testing, and thus of measurements of impact toughness.

Instrumented Drop Weight Tests. Because of the size limitations of Charpy type tests, even using fatigue cracked and side-grooved (fcsg) pieces, the degree of plane strain may be uncertain, and recognition of the instant of fracture is very difficult. A drop weight machine of moderate size was therefore constructed. The test pieces, Fig.1, normally have $a/W=0.25$, with fatigue cracked notches and side grooves 0.10 in. deep. The tup is instrumented and gauges fixed to each test piece. A gauge to measure the central bending moment, statically calibrated, is wired together with one to show the start of cracking so that there is a sudden 'kick' in the record. Deflection of the centre of the beam is also recorded by a photo cell. The output is measured in brittle tests before the shock has reflected back from the abutments. In typical tests fracture occurs in from 0.2 to 0.6 ms. Events are recorded by photographing a high speed CRO, Fig.2. No direct measurement of energy is made.

Results of the Tests. The object of the tests is twofold: to extend understanding of the mechanics of such tests by comparing data from tup, test piece gauges and deflection, and to derive impact toughness data. Comparison with 2 in. thick DCB initiation and arrest data will be reported elsewhere. Tests have been made from -150°C to about $+50^{\circ}$C on two steels, A and B (Fig.1 and Ref.10). In broad terms, there is agreement between the toughness data derived from the tup load, corrected for inertia, and the moment implied by the strain gauges. The agreement is not as close as desired. Firstly, the analogue study (7) was limited to constant velocity of tup, typical of large surplus energy in breaking brittle steel in a Charpy machine, whereas in the present machine the tup may nearly be arrested. Secondly, the analogue study covered many notch depth ratios, but only a limited number of tup contact stiffness values, again representative of Charpy type tests. Extrapolation of that data to the present test results introduces considerable margins of doubt. The third measurement, deflection, implies a certain load if the stiffness of the test beam is known. Using the static stiffness this load differs by some 50% from the strain gauge results. Stiffness is a function of time, as the deflection spreads towards the abutments, and an estimate can be made using the grossly simplified model for inertia effects of Ref.8. A ratio of dynamic/static stiffness of 1.8 is calculated for a test time of 0.6 ms. and 2.3 for a test time of 0.2 ms. These factors are of the right order, but over-correct for the effect of dynamic stiffness. Use of a distributed load to simulate a particular dynamic bending pattern also allows the computation of K for dynamic purposes. In the referenced works corrected impact loads, however obtained, have been used in conjunction with the static three-point bend formula for K. A particular pattern of bending moment distribution along the span, taken from the analogue model, is shown Fig.3, and approximations to it. Use of $S/W=2$ as approximation i) to the short effective span in an impact test reduces K slightly, as expected from static three point bend formulae for K. The effect of the reversal of bending moment (approximation ii) is to offset this trend, as can be seen by superposition of appropriate standard cases. Computation of the distributed load model itself shows that for $a/W=0.25$, span $S/W=4$ (but effectively less for dynamic reasons) the coefficient Y defining K is 2.3 instead of 1.8 for the static loading (9). Further work must be done to see how sensitive the bending moment patterns are to test variables and how sensitive Y is to such changes. The best curves of dynamic K_{1D} - temperature, based on loads inferred from the strain gauges on the beam, evaluated for $Y=1.8$ (static) and 2.3 (a particular dynamic case not necessarily representative of all the present tests) are shown Fig.4, together with early estimates for the same steels from fcsg Charpy tests (10).

Conclusions. Rough quantitative agreement has been reached between three methods of measuring impact toughness in an instrumented drop weight machine - tup load, test piece bending moment and test piece deflections, all subjected to relevant corrections. Close agreement has not yet been obtained, but the factors needing further attention seem clear. Also the dynamic bending moment distribution affects the dynamic stiffness and the value of the stress field intensity factor K, quite apart from already known inertia effects on recorded loads. One representative study shows 25% increase in K for a given load. These uncertainties are likely to mask further the effect of rate on toughness K_{1D} in such studies. Despite these uncertainties, a best representation of dynamic K_{1D} as a function of temperature up to +36°C (steel A) and +50°C (steel B) shows that earlier more approximate estimates from instrumented fcsg Charpy type tests have a surprisingly good indication of impact toughness, albeit for slightly higher strain rates.

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References

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FIG 1 : SPECIMEN AND INSTRUMENTATION

STEEL	%C	%Mn	YIELD	UTS
A	0.15	1.35	33t/in²	42t/in²
B	0.17	0.83	13t/in²	28t/in²

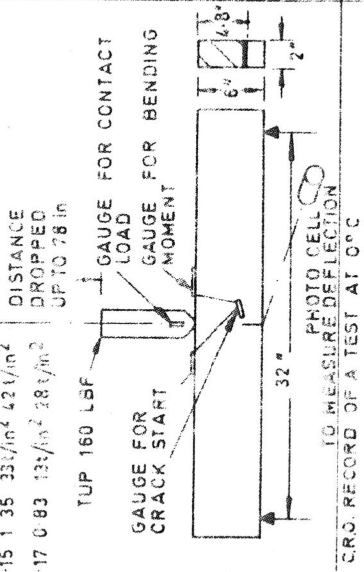

FIG. 2 : C.R.O. RECORD OF A TEST AT 0° C

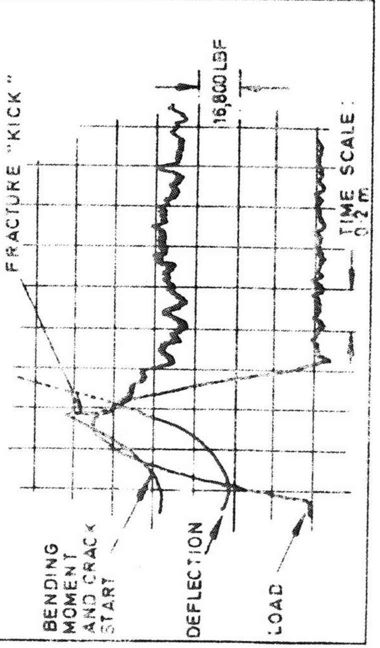

FIG. 3 TYPICAL BENDING MOMENT DIAGRAM FOR IMPACT LOADING.

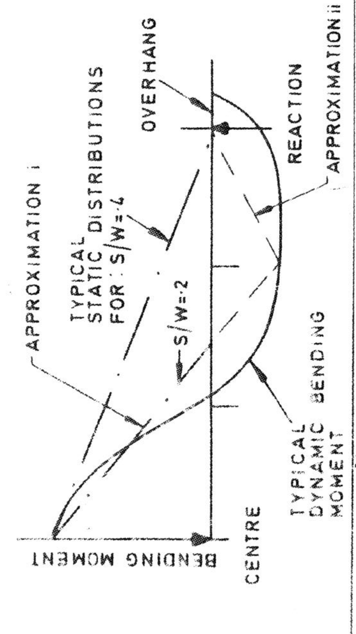

FIG 4 K_{1D} lb in$^{-3/2}$ - TEMPERATURE