THE EUROPEAN ROUND - ROBIN TEST PROGRAMME ON DYNAMIC J_{1c} AND J-R CURVE DETERMINATION

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Results are presented from a continuing round-robin test programme to compare test methods for dynamic J and J-R curve determination. This has been organised by members of ESIS TC5 Technical Sub-committee on Dynamic Testing at Intermediate Strain Rates, to provide reliable experimental data and comprehensive background information on which to develop an future international standard in this area. Good agreement has been found between results obtained on one material using a range of single and multi-specimen techniques.

INTRODUCTION

Real engineering structures may experience rapid loading by design or during emergency conditions. Thus material toughness data is often required at loading rates higher than are allowed by the existing standard methods ASTM E813 (1) and ESIS P1- 92 (2). Means for determining the fracture toughness parameter J_{1c} and for full J-R curves under rapid loading are less well understood, and numerous candidate methods of testing and analysis have been proposed (3-6). Often only small samples of material are available, but safety assesments may require at least comparative test results, even when valid results are unobtainable. There is considerable interest in using very small sub-size Charpy type samples.

No agreement has yet been reached on the best high-rate test method, nor is there a coherent body of data on which to base an informed judgement. Starting in 1991, an European round-robin test programme was organised by ESIS TC5 Technical Sub-committee on Dynamic Testing at

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Intermediate Strain Rates, in an attempt to find a solution to some of these difficulties. One material only has been used, and each participating laboratory has performed the tests using its own normal test methods. The first phase involved testing a range of specimen sizes by 7 labs, and lasted until 1994. A second phase has continued the work, concentrating on Charpy specimens and involving 6 additional participants. This paper describes the main features of the programme, and will be followed by full publication when all tests are completed and results fully assessed.

The test material, donated by Whessoe, was 50mm thick BS4360-50E structural steel whose main properties are given in Table 1, and was similar to the steel used in the recent ESIS/BCR round-robin. It was finish machined and pre-cracked by the individual labs.

TABLE 1. - Properties of BS 4360-50E Steel plate

Yield: 353MPa Tensile: 502MPa Charpy V (-50^{o}C): 133J
% C: 0.12 Si: 0.33 Mn: 0.35 Cr: 0.085 Ni: 0.15 Cu: 0.14

TEST PROCEDURES USED

The specimen types and test methods used are summarised in Table 2. Proceedures generally followed the existing multi-specimen (MS) methods ESIS P1-92 and ASTM E813-89, modified for impact velocities up to 5m/s. Some participants also used single-specimen (SS) techniques. No pre-capture signal filtration was allowed.

Test specimen geometries. Most laboratories tested variations on the precracked Charpy type, with and without sidegrooves (SG), and with a/W ratios in the range 0.3 to 0.7. In one case a modified Charpy specimen with B=10mm, W=15mm was used. A few labs with suitable testing machines were able to test large bend samples up to 50mm x 50mm.

Testing machines. Instrumented pendulum machines of 300J capacity were the most popular, with ISO and ASTM tups, but a special 600J inverted geometry machine was used by VTT (7). Other labs used large instrumented drop towers and a servohydraulic machine adapted to generate incremental displacements. Generally the force was measured from a straingauged striker, but one lab also instrumented the specimens with calibrated crack-tip gauges (8). In some cases striker velocity was measured just before impact, but in general velocity or displacement during the test was not measured directly. The main test methods were :-

Multi Specimen The 'Reduced Velocity', also known as the 'low blow' test, varies the impact energy to produce different amounts of crack growth. The loading rate decreases during the test, and final velocity is zero. Initial striker velocities ranged from 0.5 to 2.5m/s. In the Chipperfield method,the

Table 2 - Summary of Interim Results of ESIS TC5 Round - Robin Test Programme on Dynamic J Testing at 10. 3. 1996

Institute	**Specimen type**	**Testing method**	**Critical J-integral value according to ASTM $J_{0.2/BL}$ kJ/m^2**	**Critical J-integral value according to ESIS P1 $J_{0.2/BL}$ kJ/m^2**
CISE, Milan, Italy	Charpy, SG	multi-specimen	448	550.3
Fraunhofer-Inst. für Werkstoffmechanik, Freiburg (Fh-IWM), Germany	Charpy, SG	single specimen	609.9	592.3
		multi-specimen	398.6	422.5
University of Miskolc (UM), Hungary	Charpy, SG	multi-specimen	477.1	488
VTT Techn. Res. Centre of Finland	Charpy, SG	single-specimen	ESIS3 479 ESIS2 650.2	460.8 650.5
VTT Techn. Res. Centre of Finland	Charpy	single specimen	1075.6	1075.4
Ruhr University (RU) Bochum, Germany	Charpy	multi-specimen	654.6	613.7
EMPA Mat. Testing Lab., Switzerland	Modified Charpy (10x15)	single-specimen	929.7	918.1
Fraunhofer-Inst., Freiburg	SENB 3PB, SG (50x50)	multi-specimen	577.1	471.7
The Welding Institute (TWI), UK	SENB 3PB (20x40)	multi-specimen	516.4	466.1
Imperial College (IC), UK	SENB 3PB (20x40)	multi-specimen	1546.7	1765.2
	SENB 3PB (40x40)	multi-specimen	1031.2	884.9
Imperial College (IC), UK	SENB 3PB (20x20 stat.)	multi-specimen	314	?

striker energy is sufficient to ensure constant velocity through the test. The specimen is machined with narrow shoulders which rest on the supporting anvils (6). Impulse Loading uses a servohydraulic machine programmed to perform a single triangular wave for each test. By adjusting displacement incrementally, specimens were deformed to produce variable amounts of crack growth at approximately constant rate.

Single Specimen Methods. These included a Double Displacement ratio method, with dynamic COD measured laser reflection to detect crack initiation (7). Other Key Curve methods were used, generating an R-curve from information extracted from the the measured load-displacement curve (10). Additionally the strain at peak load or dynamic yield stress is needed.

RESULTS AND DISCUSSION

A typical force-displacement-time record for a reduced velocity Charpy test is shown in Fig 1. Ringing effects decrease in magnitude after 3 or 4 oscillations, and are negligable once maximum force is reached. Integration of the force curve up to $v = 0$ gives, after correction for elastic effects, the energy for crack growth. Accuracy can be checked by comparison to pendulum potential energy.

Fig. 2 shows single and multi-specimen J-R curves obtained for Charpy SG specimens. A good correlation is evident, with mean $J_{0.2BL}$ of 527kJ/m^2 and most data contained within a std. deviation band of 78kJ/m^2. The blunting line calculated by the ESIS method using a dynamic yield stress of 650MPa gives a good fit to the data, which is outside the validity limits for both J_{max} and Δa_{max}, as expected for such small specimens.

For comparison, Fig 3 shows curves for plain Charpy specimens, analysed using ASTM procedures. The ASTM blunting line slope is clearly inappropriate, but the ESIS derivation again fits reasonably to the data. The single specimen curves show remarkable agreement, particularly since VTT obtained almost identical curves from two further specimens. The mean $J_{0.2BL}$ is 869kJ/m^2 reflecting lower constraint, and spread of data is greater with a std. deviation of 190kJ/m^2. The scatter may be due to differences in precracking, calibration, and crack length measurement methods. CISE reported only minor variation in energy attributable to the different geometry of ASTM and ISO tups.

There are limited results for the larger specimens, but those from Fh-IWM and TWI group well. The IC specimens were not side grooved, and testing was concentrated at large crack growth where for this steel, fracture is dominated by shear. The fracture mechanism is complex and the crack length measurement problematic. Further tests with SG specimens are planned.

CONCLUSIONS

Results show promise that dynamic methods can yield reproducible data for both small and large specimens. Extra insight into factors influencing dynamic elastic-plastic fracture processes will be obtained by combining the mainly experimental work of the TC5 group with the interesting results being explored by numerical methods, or by considering the effect of a two-parameter theory applied to dynamic loading conditions (10, 11). If the results still outstanding confirm the trends already noted, work should start on a draft Charpy J method, incorporating one single and one multi-specimen technique. Then a draft for a full-size dynamic J method should be produced, and perhaps a further round-robin considered, using another material and closely-controlled test procedures.

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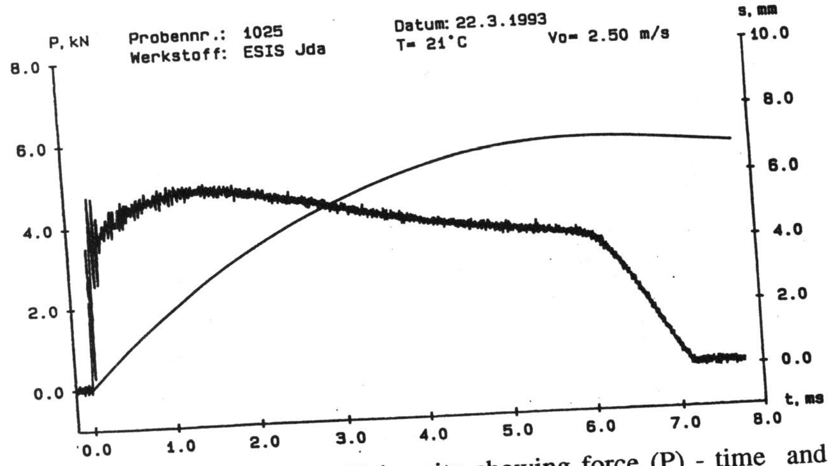

Figure 1 Record from Ruhr University showing force (P) - time and displacement (s) - time for a reduced velocity Charpy test

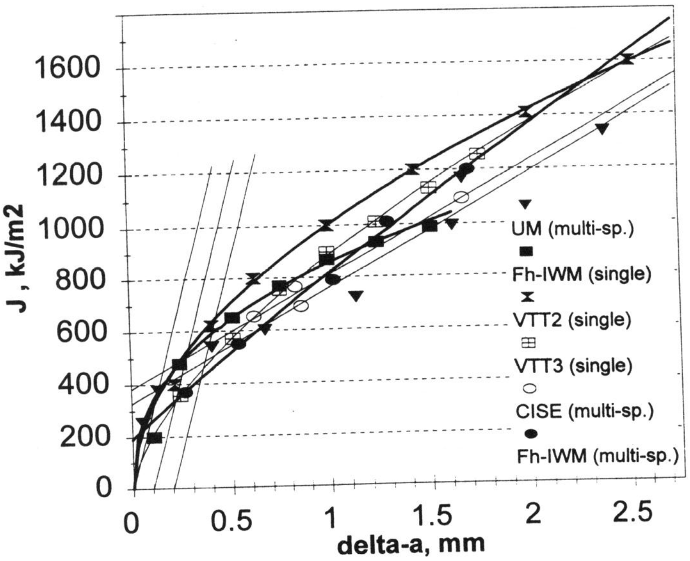

Figure 2 J - R curves for side - grooved Charpy single and multi specimen tests with blunting and exclusion lines to ESIS P1-92

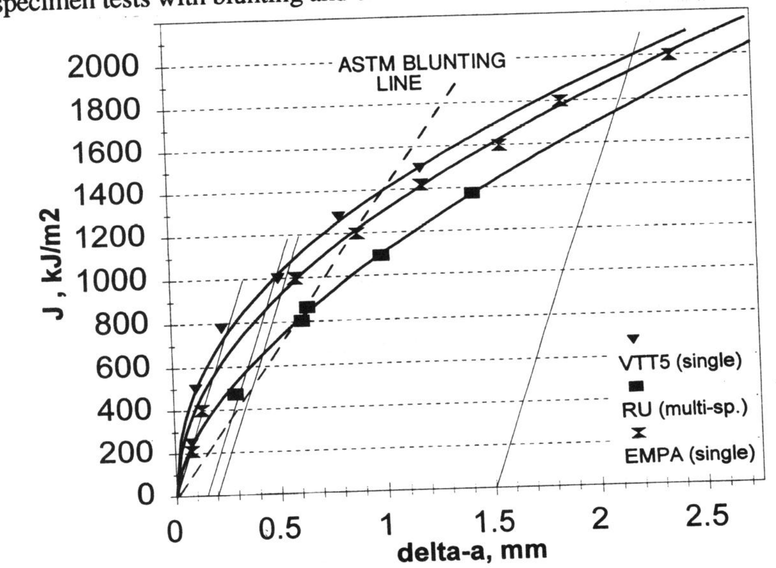

Figure 3 J - R curves for plain Charpy single and multi - specimen tests using ASTM E813 showing ASTM & ESIS blunting line slopes