DYNAMIC COMPRESSION TESTING OF METALLIC MATERIALS EUROPEAN PROGRESS TOWARDS A TEST STANDARD

A. DOIG[1], N.MORGAN[1] AND H. TAYLOR[2]

[1] *Centre for Materials Science and Engineering, Cranfield University, Royal Military College of Science, Shrivenham, Swindon, SN6 8LA, UK*

[2] *Department of Mechanical Engineering, Design and Manufacture, Manchester Metropolitan University, Manchester, M1 5GD, UK*

ABSTRACT

This paper describes progress of the European Structural Integrity Society ESIS, committee TC5, towards a proposed European Standard for Dynamic Compression Testing of Metallic Materials at room temperature. The problems of compression testing using solid cylinder specimens are discussed, with suggested ways to overcome some. A draft standard has been written, proposing 4 test methods. They are outlined together with early experiences of round-robin testing.

KEY WORDS

Compression testing, Dynamic, Test standard.

INTRODUCTION

ESIS technical sub-committee TC5 is interested in mechanical testing of metallic materials at strain rates up to about 10^4 s^{-1} - ‘dynamic testing at intermediate strain rates’. A conventional tensile test on a 50 mm gauge length specimen is usually done at a crosshead speed no higher than 10 mm per minute, giving a strain rate of about 3.10^{-3} s^{-1} - ‘quasi-static testing’. For dynamic testing of sensible sized specimens, crosshead speeds should be above 1 m s^{-1} and so instrumented Charpy pendulums, high speed servo-hydraulic test machines and instrumented drop towers are used.

Over the past 12 years or so TC5 has been developing European test standards, starting with dynamic fracture toughness K_{Id} on pre-cracked Charpy specimens. Subsequent work has included dynamic tensile testing and most recently dynamic compression test methods.

Compression Testing

Most compression testing is done on solid circular cylinder specimens squeezed between plane platens. This gives rise to significant frictional forces acting on the cylinder end-faces, which then cause artificially high load values at the load cell. The most well known existing test standard for metallic materials is ASTM E 9 - 81 [1] and it recommends reducing end-face friction by using PTFE shims or fluid lubricants. Diameter to length ratios D_0/L_0 of solid cylinder specimens are usually between 3/1 and 0.5/1. Shorter fatter cylinders tend to 'barrel' as they compress, and longer thinner cylinders tend to buckle or shear off-axis. However, the ASTM standard only applies for quasi-static strain rates of up to 0.005 min^{-1} or $8.3x10^{-5}$ s^{-1}.

Dynamic Compression Testing

Extra difficulties encountered as the strain rate is increased include :-

- Load signal 'ringing' - caused by resonance frequency effects, requiring a transient recorder frequency response of better than 1MHz to cope. Figure 1 shows the unfiltered piezo-crystal load cell output from a well optimised instrumented drop tower rig, together with the smoothing construction for the yield load. It is common to electronically smooth the load signal, but only with great care.

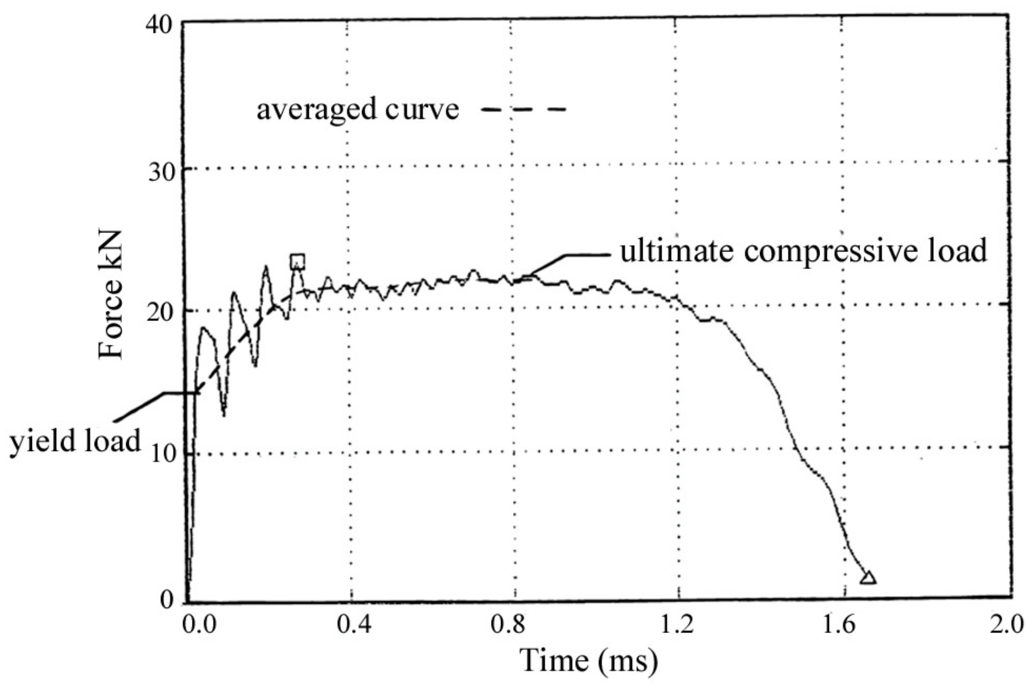

Figure 1: Raw dynamic compression test curve for tungsten alloy solid cylinder

- Adiabatic heating - due to the rate of heat generation by plastic deformation exceeding the the rate of heat loss to the surroundings. Work hardening is overcome by this thermal softening, giving a new meaning to term Ultimate Compressive Stress.

- Adiabatic shearing - a sudden strength drop usually due to localised microstructural changes. Some alloys are more prone to this, as are longer thinner test cylinders. Both adiabatic effects are seen in Figure 2.

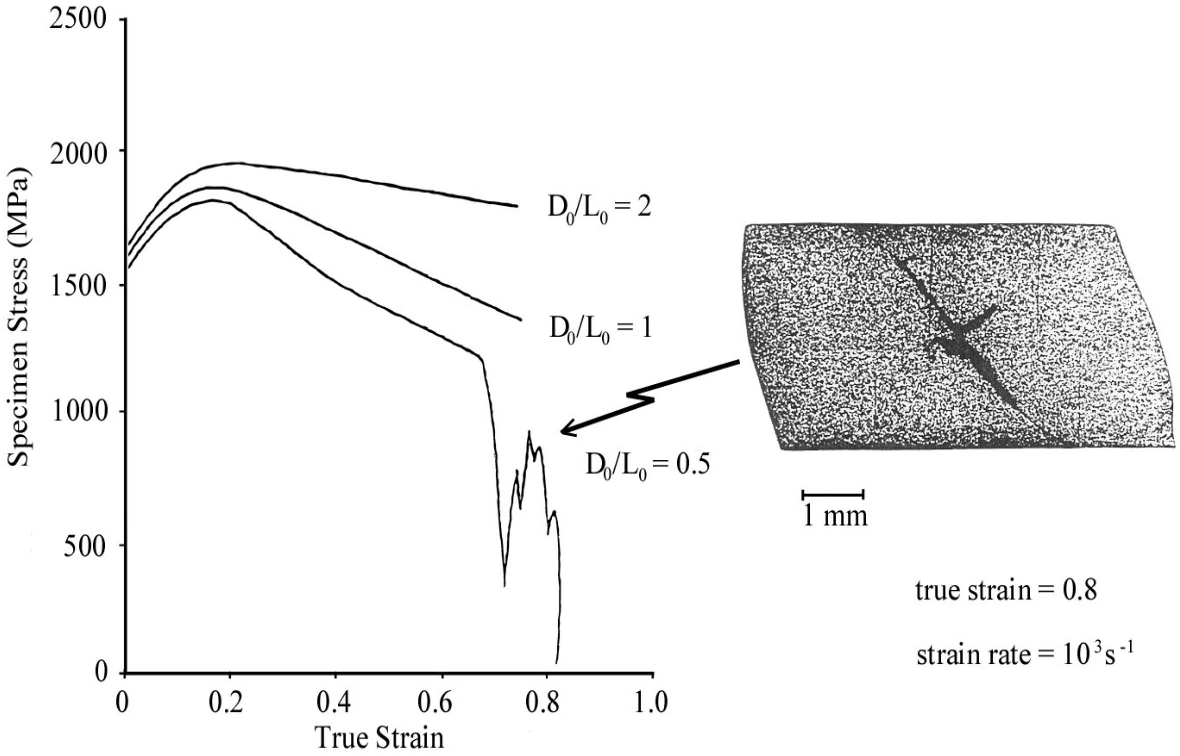

Figure 2: Dynamic compression curves for 3 tungsten alloy cylinders, adiabatic shearing occurring in the thinnest - with its cross-section macrograph alongside [2].

THE DRAFT STANDARD

A draft standard has been written encompassing the following 4 possible test methods, each with a different way of tackling the main problem of test specimen end-face friction.

Method 1 : Reducing Friction with PTFE Shims

This is the previously mentioned ASTM method [1] adapted for higher strain rates.

Method 2 : Reducing Friction with a Rastegaev Specimen and Lubricating Bags

The solid cylinder Rastegaev specimen [3] has slight recesses machined on its end-faces to accomodate lubricating bags, usually containing thick oil. Figure 3 shows that this eliminates barrelling of medium strength steel specimens at strains of less than 60%. Figure 4 shows that this method reduces friction more than just using the same lubricant on the plane ends of conventional solid cylinder specimens.

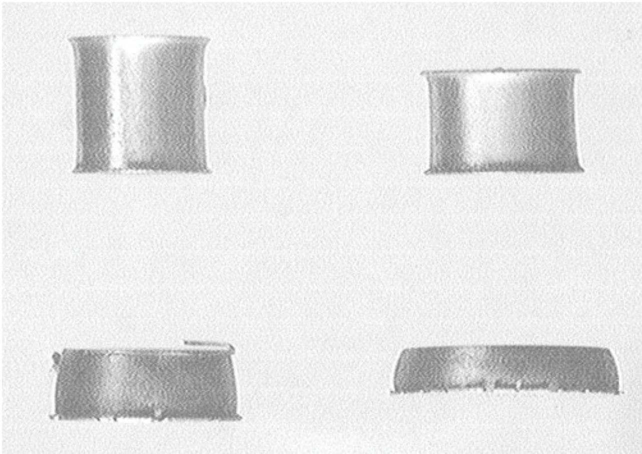

Figure 3: 20MoCrS4 steel Rastegaev specimens with strains of 20, 40, 60, 80% - lubricant Nomynol VI 1200-BF; strain rate 1.3 x 10^2 s^{-1} [4]

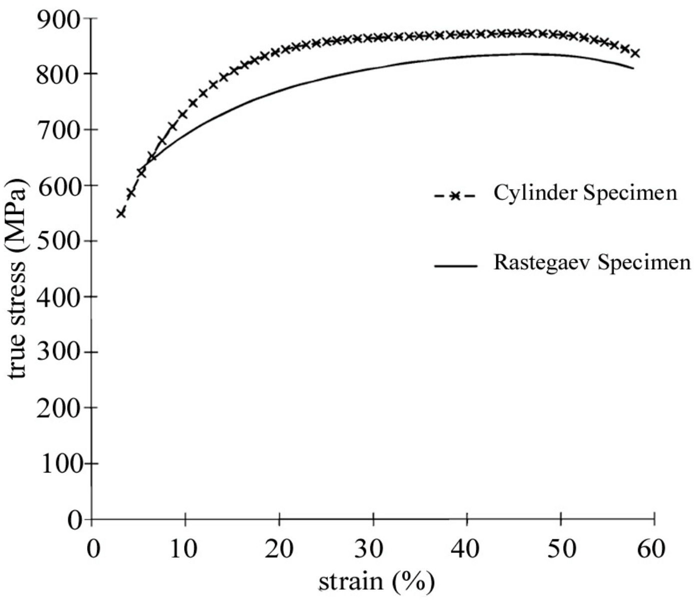

Figure 4: 20MoCrS4 steel compression curves, for a lubricated solid cylinder specimen and a Rastegaev specimen - lubricant Nomynol VI 1200-BF; strain rate 1.3 x 10^2 s^{-1} [4]

If complete stress-strain compression curves are required (to measure a full range of flow stresses for mathematical modelling purposes say) then it is recommended that end-face friction errors are eliminated altogether, using one of the following two methods.

Method 3 : Eliminating Friction Using a Ring Test to Determine μ

A solid cylinder specimen is first tested, followed by a sister hollow cylinder specimen (ring test specimen) which is used to determine the coefficient of friction μ between the solid cylinder end-faces and the platens from a nomogram [5]. Then raw stress values can be accurately corrected downwards. The ring specimen must have the same outside diameter and length as its sister solid specimen, and the ratio of its outside diameter to inside diameter has to be 2:1. Also the conditions for both tests have to be the same, including the strain, the strain rate, the temperature and the lubricant.

Method 4 : Eliminating Friction Using The Cook and Larke Method

The Cook and Larke method [6-source, and 7] tests 4 sister solid cylinders with different D_0/L_0 ratios. Then iso-strain stress lines can be extrapolated back to zero D_0/L_0 as seen in Figure 5, and these stress values reconstituted into a friction free compression curve.

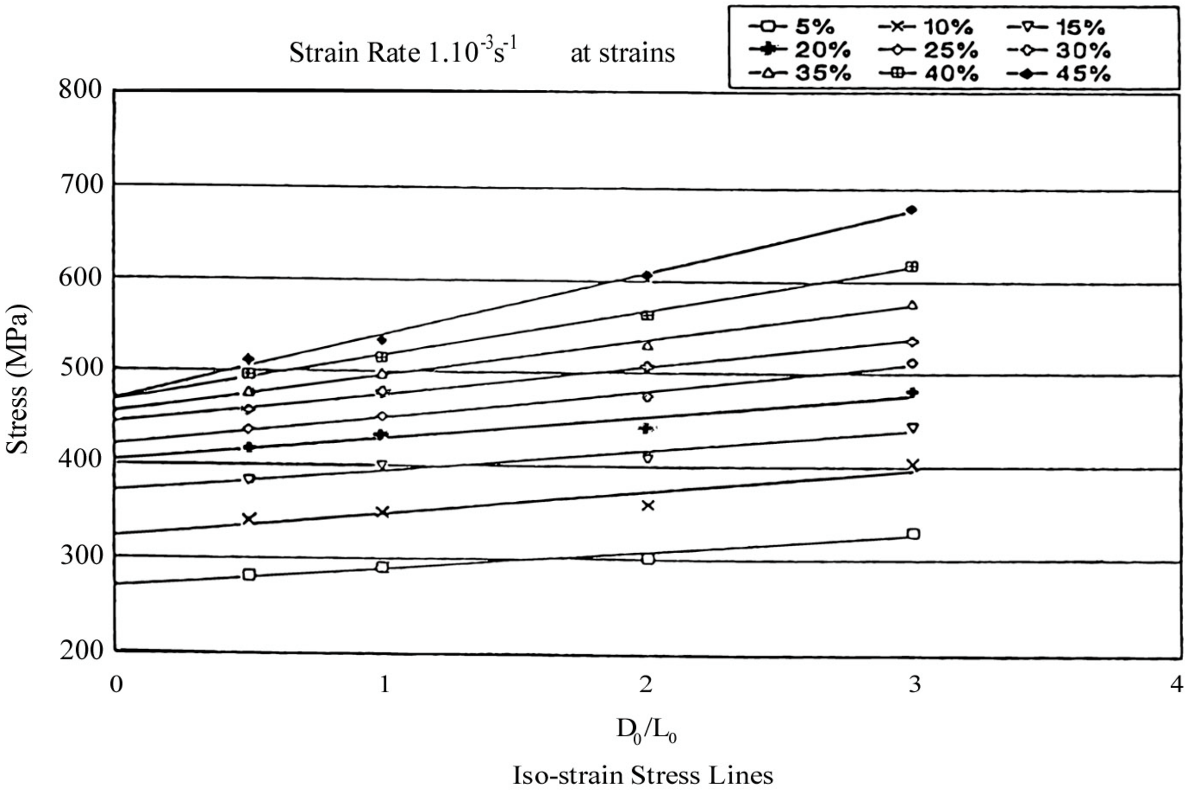

Figure 5: The Cook and Larke construction for eliminating end-face friction during compression testing of mild steel solid cylinders [8]

Specimen lubrication is neither necessary nor desired, since accurate extrapolation relies on consistency of end-face surface finish specimen to specimen - a set being typically all '0000' emery for example. When testing a series of cylinders experience has shown that this is usually best done by keeping D_0 constant and varying L_0, even though this means varying the strike speed to maintain constant initial strain rate.

The Cook and Larke method is often regarded as the better way to obtain friction free stress-strain compression curves, but the disadvantage is having to test several specimens for one determination.

ROUND-ROBIN TESTING

Having written the draft standard incorporating the above 4 methods, ESIS TC5 has started round-robin testing with mostly 5 mm diameter specimens of (a) pipe steel A533B 20MnMoNi 5 5 and (b) titanium alloy Ti-6Al-2Nb-1Ta-1. The latter alloy was chosen since it is one that readily exhibits adiabatic shearing.

Results from 9 different laboratories across Europe are gradually coming in for collation. There are several issues to tackle further, such as how best to correct for test machine compliance. Then the draft standard can be refined before final issue.

CONCLUSIONS

A draft dynamic compression testing standard has been written incorporating 4 possible test methods, and round-robin testing of them is currently underway. It will be some time yet before the dynamic compression test methods can be properly standardised, but ESIS TC5 will continue working in this area and is still open to consider other compression test methods.

The requirement for dynamic materials properties of all kinds is increasing. In everyday life there is very little quasi-static plastic deformation and we are learning that dynamic mechanical properties can be very different, usually with higher strength but lower ductility. Strain rate sensitivity varies with microstructure as well as with alloy type, so that the usual ‘mechanical property database’ in the heads of materials engineers and mechanical designers is unrealistic. A prime example is vehicle crashworthiness where computer models need to incorporate dynamic mechanical properties (rather than the readily available but inaccurate quasi-static properties as mostly used at present) for them to stand any chance of being used predictively.

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