DYNAMIC COMPRESSION TESTING OF PLAIN CARBON STEEL

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In a dynamic compression test deformation is found to be non-uniform due to end face friction. The effects of friction can be eliminated by the use of the cook and Larke method, but this is normally applied to solid test cylinders. In a solid cylinder the material at the centre is heavily constrained and hollow cylinders are used to reduce this effect. These cylinders are normally large and beyond the load capacity of dynamic tests. A comparison between conventional solid cylinders and some having a small axial hole is presented. The use of conventional sized cylinders results in acceptable loads during dynamic testing. The results from a series of plain-carbon steel test specimens are analysed by the application of the Cook and Larke method.

INTRODUCTION

The strain in a tensile test is normally uniform up to the point of general instability or necking when the deformation become non-uniform. The compression test may be used in cases where true stress data is required at large strain values in the assumption that instability is suppressed and the strains stay uniform (1). The conditions experienced during a dynamic compression test do not stay constant, but will vary continuously throughout the duration of the test. When using a drop tower the nominal strain rate will reduce during deformation. Heating of the test specimen will occur and this will be concentrated within shear bands undergoing the most deformation.

End face friction will cause the test specimen behaviour to be dominated by the local behaviour within the deformation zones. The local strains within the zones will be higher than the net strain and similarly the strain rates encountered will also be higher. As the temperature within the deformation zone increases the local yield stress will decrease and the thermal conductivity also decreases with increasing temperature. If work hardening dominates, the shear bands will broaden, but if thermal softening dominates, the bands will become narrower leading to instability.

Using hollow, rather than solid cylinders can reduce the non-uniform strain. Conventionally, hollow cylinders are larger than the solid cylinders used for dynamic testing which means that the energy requirements to cause significant deformation will be

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unobtainable in many cases due to the capacity of the test machines. The use of smaller size hollow cylinders necessitates the use of a small diameter axial hole which will change the degree of constraint on the material in the specimen but this may not be significant compared to the end-face friction effect.

End face friction can be counteracted or eliminated by the use of lubricant, hollow cylinders, dished cylinders or by use of the Cook and Larke (2) method, where cylinders of different diameter to length ratio (D/L) are tested with no lubrication. In the Cook and Larke method, iso-strain lines are extrapolated graphically back to zero D/L to give friction free values as demonstrated by Singh (3) and Belk (4). When using the Cook and Larke method, different D/L ratios can be obtained by either varying the diameter of specimens of fixed length or by varying the length of specimens of fixed diameter.

EXPERIMENTAL METHOD

A series of compression cylinders were machined from plain carbon steel of 0.2% Carbon and were tested dynamically at two D/L ratios of 0.63 and 0.8. The cylinders were machined in various lengths and tested at the appropriate initial velocities to give the same initial strain rate of 4 x 10^2/sec. The specimens were prepared with the same end face surface finish to provide matching end face friction effects without the use of a lubricant. All the compression tests were conducted at 20°C using an instrumented drop-tower having an energy input of approximately 100J, using hardened and polished compression platens. The instrumentation consisted of a strain gauged cylindrical load cell with a 200kN capacity connected to a dynamic strain amplifier and a PC based high speed data acquisition system running at a sample rate of 1MHz. The yield loads were extracted from the recorded data and divided by the initial cross sectional areas to give dynamic 'yield' stress values. The yield stresses were than used in a Cook and Larke analysis at the two D/L ratios of 0.8 and 0.64. This method of analysis gave a single iso-strain value, which could be extrapolated back to zero D/L to give friction-free yield stress values.

RESULTS AND DISCUSSION

Table 1 shows the dimensions of the test specimens used in this work along with the corresponding initial velocities to produce a constant initial strain rate of 4 x 10^{-2}. Three solid cylinders of each size were tested along with three hollow cylinders having the same nominal lengths and diameters as those in the table with the inclusion of a 2mm diameter central hole. This resulted in eight groups of test specimens (four solid and four hollow) at two D/L ratios. This combination allowed the direct comparison of results from specimens of different diameters and fixed D/L with other specimens having different lengths and fixed D/L, as well as seeing the effect of a small central hole. The values of yield load were obtained directly from the force-time graphs for each specimen. The values of yield force were converted to engineering stress values by dividing the forces by the corresponding initial cross sectional areas. The yield stress values for each group of test specimens were averaged and plotted on a diagram of stress vs. D/L in each of the eight cases.

Length (mm)	Diameter (mm)	D/L Ratio	Velocity (m/s)
12.6	8.0	0.63	5.04
10.0	8.0	0.80	4
10.0	6.3	0.63	4
7.9	6.3	0.80	3.16

Table 1. Lengths and diameters used in the dynamic compression tests.

Figure 1 shows a Cook and Larke extrapolation for the mean of all the dynamic compressive yield stress values (YS_{DC}) back to a friction free value of zero D/L. Examination of this graph shows that the hollow cylinders require more stress to cause yielding in this material and would indicate that the hole results in increased friction rather than less as may be expected. This effect is most noticeable in the shorter length/larger diameter test specimens. There is some difference observed between the specimens with different diameters and those with different lengths to achieve the required D/L ratios. Where the length is changed by a small amount to vary D/L, the stresses at the alternate D/L are found to be very unpredictable (due to the relatively large scatter in the values of stress obtained).

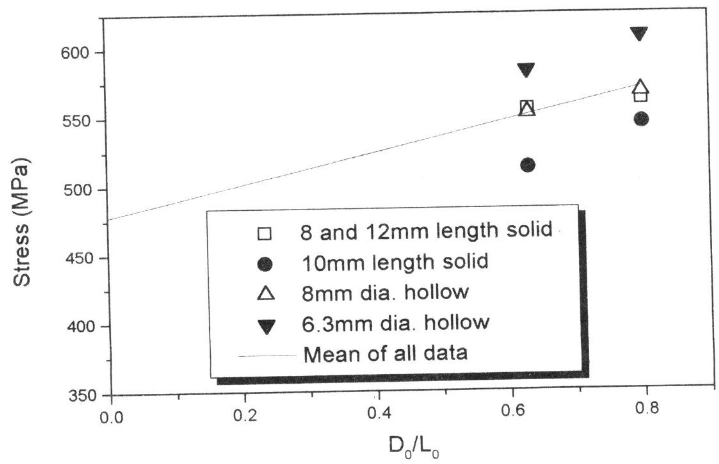

Figure 1. Cook & Larke extrapolation for all samples tested.

The resulting Cook and Larke extrapolations are then not satisfactory and would give very large increases or reductions in stress at zero D/L ratio. Where the variations in lengths are larger (from 7.9 to 12.6mm) the Cook and Larke extrapolations are as expected i.e. decreasing towards zero with approximately 20% reduction in stress at zero D/L ratio. It must be noted however, that these larger changes in length also involved differences in diameter.

Table 2 shows the friction correction factors obtained for this steel and test condition. The friction correction factor was around 20% at the 500 Mpa YS_{DC} level, in keeping with other findings (5). This extrapolated value is typically greater than the compression tests performed pseudo-statically, which gave almost identical yield stress values of approximately 350 Mpa both with and without lubricant.

Mean Yield Stress Measured at D/L = 0.8 (Mpa)	**Frictionless Yield Stress at D/L = Zero (Mpa)**	**Component of Ys_{DC} Measured at D/L = 0.8 Due to Friction (%)**
570	478	19.3

Table 2. Friction correction at D/L = 0.8.

CONCLUSIONS

- The dynamic compressive friction free yield stress can be determined from a Cook and Larke analysis of the force time results.
- The use of hollow cylinders with a small diameter axial hole increased the observed yield stresses.
- Small variations in the lengths of test specimens of the same diameter were found to be unsatisfactory in a Cook and Larke analysis.
- Variations in diameter of the test specimens resulted in satisfactory extrapolation to zero D/L ratio.
- The mean stress values at each D/L ratio extrapolate to give a meaningful dynamic compressive yield stress for this material.

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