Aspect ratio compression effects on metals and polymers

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Abstract. Previous research has studied the effects of altering the shape and size of samples over a range of compression rates. Several discrepancies exist in the published data, probably due to the wide range of techniques used. The research here was carried out to bridge this gap. Cylindrical polycarbonate and aluminium (6082) samples, with varying aspect ratios, were subject to a range of strain rates between $10^{-4}$ - $10^{2}$ s$^{-1}$, with further data gained for polycarbonate at higher strain rates between $10^{2}$ - $10^{3}$ s$^{-1}$, and the stress-strain relationships obtained, compared and discussed.

1. Introduction
The range of strain rates examined here were achieved using quasi-static, drop-weight tower, and Split Hopkinson Pressure bar (SHPB) techniques. All the experiments were carried out at ambient temperature and humidity.

To ensure the validity of results for a given experimental technique, sample dimensions and ratios must complement the load and loading rate. For example, in Split Hopkinson Pressure Bar experiments, it is important that stress equilibrium is reached inside the specimen: the sample should be sufficiently thin to obtain $>3$ internal reflections of the stress wave. The sample diameter should be both less than the diameter of the bars, and sufficiently small to ensure that any stresses due to radial inertia are negligible [1].

Here we present results over a wide range of strain rates. The effects of sample geometry on the mechanical behaviour of aluminium 6082 and polycarbonate are investigated.

Polycarbonate is an amorphous thermoplastic polymer with high transparency and toughness, and has a large variety of applications. It has an average density of 1.20 g cm$^{-3}$ and a glass transition temperature of $+148^\circ$C. The aluminium 6082-T6 (BS EN755) has a density of 2.70 g cm$^{-3}$ and a melting point of $+650^\circ$C. The chemical composition in this aluminium alloy is 0.97% silicon, 0.71% magnesium and 0.51% manganese, with trace amounts of iron, titanium, copper, zinc and chromium. The alloy has been solution heat treated and artificially aged (precipitation hardened).

Cylindrical samples have been machined to a constant diameter of 4 mm and thicknesses of 1 - 12 mm. The samples will henceforth be designated by their aspect ratios (ratio of length to diameter), and will range between 0.25 - 3.
2. Low Strain Rate Effects
A 250 kN universal testing machine Instron (model 5584) in the Mechanical Engineering Department at Imperial College London was used. The apparatus is a servo-hydraulic machine, and can be used in both compression and tension.

Under compression, the machine is designed to load uniformly and compress a specimen, until a pre-defined limit. The tests performed here reached completion when 50% of the original specimen height was reached, a force of 90 kN was obtained, or the material fractured. A compression rate of 0.004 mm s$^{-1}$ was adopted, resulting in strain rates between $10^{-4}$ - $10^{-3}$ s$^{-1}$.

As can be seen from figure 1, despite differences in strength, the strain rates experienced by material samples with the same aspect ratio were almost identical. However, this trend decreased as the aspect ratio decreased. As the aspect ratio increased, i.e. at greater thicknesses per fixed diameter, the strain rate achieved decreased.

As the aspect ratio for samples increased, the slope in the elastic region steepened, indicating a stiffer response at higher aspect ratios. Buckling was seen in aluminium samples with an aspect ratio of 3, and in polycarbonate samples with aspect ratios larger than

![Figure 1. Strain rates achieved for both aluminium and polycarbonate samples of varying aspect ratios from quasi-static experiments.](image1)

![Figure 2. Quasi-static stress-strain data for Al 6082.](image2)
1.8.

As expected, aluminium supported far larger stresses than polycarbonate. Yielding in aluminium (see figure 2) occurred at 170±10 MPa for all samples with aspect ratios greater than 0.75, and in polycarbonate (see figure 3) at 70±7 MPa for all samples with aspect ratios larger than 0.5. These values agree well with average values on data sheets presented by a number of material production companies; 175 MPa for aluminium 6082 and ∼80 MPa for polycarbonate.

3. Drop-Weight Testing

Drop-weight tests yield strain rates of the order of $10^2 \text{ s}^{-1}$. Here, the spring-loaded Instron (Dynatup) 9250HV machine in the Civil Engineering Department at Imperial College London was used. It consists of a (variable) mass holder, which slides between two external guiding rods, and is fitted with an accelerometer. Arresting brakes are mounted at the base to prevent the mass from impacting the specimen more than once [2].

An impactor mass of 8.5 kg, and an impact velocity ∼3 m s$^{-1}$, was adopted. A high-speed video camera, the Phantom V12.1, was used to image the deformation behaviour of specimens.

From the obtained high-speed images (figures 4-7, it can be seen that both polycarbonate and aluminium deform plastically, and show large applied strains. As expected, aluminium is able to support a larger applied load than a polycarbonate sample of the same aspect ratio, as

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Figure 3. Quasi-static stress-strain data for polycarbonate.

Figure 4. Drop-weight sequence showing the behaviour of an aluminium cylinder, aspect ratio 1 (diameter = height = 4 mm), during impact (mass 8.5 kg, impact velocity ∼3 m s$^{-1}$).
can be seen in figures 4 and 5.

At aspect ratios larger than 1.8, we see obvious buckling in polycarbonate (see figure 6), and the start of buckling in aluminium. This buckling effect in aluminium is far more pronounced in the aluminium cylinders with aspect ratios equal to 3, as shown in figure 7.

4. Split Hopkinson Pressure Bars
A SHPB (see figure 8) was used to reach strain rates of the order of $10^3 \text{ s}^{-1}$ [3]. The specimen sample is placed between the input and output bars. A small gas gun is used to launch the striker bar against the input bar. Semiconductor strain gauges in the centre of the input and output bars [4] measure the elastic waves which propagate, and record the incident, transmitted and reflected pulses [5]. The resistance change from the strain gauges is recorded [6]. If the specimen is in stress equilibrium (>3 reverberations), the rate of deformation is directly proportional to the amplitude of the reflected stress wave. The amplitude of the transmitted wave is directly proportional to the stress the specimen supports [7].

The results presented here are from preliminary experiments carried out on polycarbonate samples. Firing pressures were varied from 2 - 3 bar, with striker bars of different lengths (18.2 cm and 23.1 cm), resulting in velocities from 7 - 9 m s$^{-1}$. Only two aspect ratios (0.5 and 1.0) were tested here. Strain rates of between 1950 - 5800 s$^{-1}$ were achieved.

![Figure 8. Schematic of a Split Hopkinson Pressure Bar.](image-url)
As can be seen from figure 9, the higher the aspect ratio, the lower the strain rate. The lower the aspect ratio, the larger the effect of the striker bar length at the higher firing velocities.

From figure 10, it can be seen that the obtained peak stress was between 110 - 130 MPa, regardless of impact conditions. An identical post-yield softening was also observed, although larger aspect ratios experienced lower applied strains. It was seen that there was strain softening at the beginning, and that the general elastic-plastic behaviour expected from polycarbonate samples under these compression rates was also observed. After achieving peak stress, the specimens continued to deform at decreasing stress levels until a strain of 0.1 - 0.2 for higher aspect ratios, and until strains greater than 0.25 for lower aspect ratios.
5. Conclusions and Future Research
We present here initial results from low to mid-strain rate experiments conducted on polycarbonate and aluminium samples of different aspect ratios.

Both materials behave as expected from current, available, literature, and the data across the different compression rates demonstrates the same trends for the same aspect ratios.

Based on these preliminary findings, we can conclude that we have a wider range of consistent aspect ratios to choose from when using aluminium, at least 0.5 - 2, but a narrower range for polycarbonate, around 0.5 - 1.5, before the material succumbs to buckling.

Further research will be carried out at dynamic strain rates for these two materials, and all experiments repeated for several other materials, including copper, titanium and lead zirconate titanate (PZT). This research will focus singularly on measuring their material properties, not the combined structural and material response.

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