# UNIAXIAL COMPRESSION EXPERIMENTS OF CERAMICS AT QUASI-STATIC AND DYNAMIC STRAIN RATES

Zhiyong Wang[*], Peifeng Li[*a)]

[*]*School of Mechanical & Aerospace Engineering, Nanyang Technological University,639798, Singapore*

*Summary* Compressive behaviour of alumina was measured at the strain rates of $10^{-4}$ and 650 $s^{-1}$. The influence of specimen aspect ratio and lubrication on compressive strength was investigated under quasi-static loading rates. Both the quasi-static tester and the modified split-Hopkinson pressure bars (SHPB) were experimentally instrumented to improve the accurate measurement of elastic strains as well as failure strains of alumina. It was found that alumina does not show strain rate dependency under the strain rates up to 650 $s^{-1}$.

## INTRODUCTION

The investigation of response for ceramics has become more and more attractive for the past decade. Efforts have been made to understand the stress-strain behaviour, damage evolution and failure modes in ceramics at different loading rates. However, there still exists controversy over many aspects due to a lack of sufficient experimental datum. Researchers have focused on testing of ceramics subjected to uniaxial compression widely utilized and capable of observing and quantifying the response of materials at strain rates ranging from $10^{-4}$ to 5000 $s^{-1}$ [1, 2]. Though care has been taken during the experiment (e.g. with lubrication), multiaxial stress state inevitably presents in the compression test specimen due to the appearance of friction [3]. The interfacial frictional effect in a compression test can be expressed [4]:

$$\bar{P} = (1 + \frac{\mu}{n} \cdot \frac{d}{l})\sigma_y \quad (1)$$

where  is the applied mean pressure, $\mu$ is the coefficient of friction, $n$ is a number correlative with type of lubricant, $d$ and $l$ are the diameter and length of a cylindrical specimen, respectively, and $\sigma_y$ is the intrinsic yield stress of the material (when $\mu$=0). As the measured stress is a combined function of lubrication and the aspect ratio of specimens, a reasonable aspect ratio should be selected to improve the measurement accuracy. There is little study focusing on specimen aspect ratio and lubrication effects on uniaxial compression experiments of brittle materials such as alumina. The aim of this study is to accurately measure the compressive behaviours of alumina under quasi-static and dynamic loading rates (approximately $10^{-4}$ and 650 $s^{-1}$). The experiments were performed on specimens as a function of aspect ratios ($l/d$= 1 and 2.4) and lubrication in quasi-static compression experiments. Accurate measurement of strain in the compression was investigated for both quasi-static and dynamic rate experiments.

## EXPERIMENTAL INVESTIGATIONS

Cylindrical alumina (>99% $Al_2O_3$) specimens with diameter of 5mm were used with the length of 5 and 12mm, making aspect ratios of 1 and 2.4, respectively. Uniaxial compression tests were conducted using: (1) a screw-driven test machine (INSTRON) at quasi-static strain rates (~$10^{-4}$ $s^{-1}$), (2) a modified SHPB at high strain rates(~650 $s^{-1}$). Lubricated and unlubricated specimens with $l/d$= 1 and 2.4 were tested at each strain rate; at least three repeats were performed.

In the quasi-static tests, an extensometer and calibrated load cell was used to measure the displacement and the applied force, respectively. In the high strain rate experiments, a strain gauge was mounted directly on the surface of specimens to record the strain history, as the failure strain of ceramics is low. Surface strengthened platens were used to minimize stress concentration and to avoid indentation. Additionally, a pulse shaper was recommended to be employed to avoid the jump of the strain rate.

Engineering stress and strain at low loading rates were calculated based on the measured force and displacement, respectively. For dynamic experiments in SHPB, one-dimensional elastic wave equation was used to calculate the strain from the reflected pulse and the corresponding stress from the transmitted pulse. However, the strain was corrected by the direct measurement of strain history in the strain gauge mounted on the specimen.

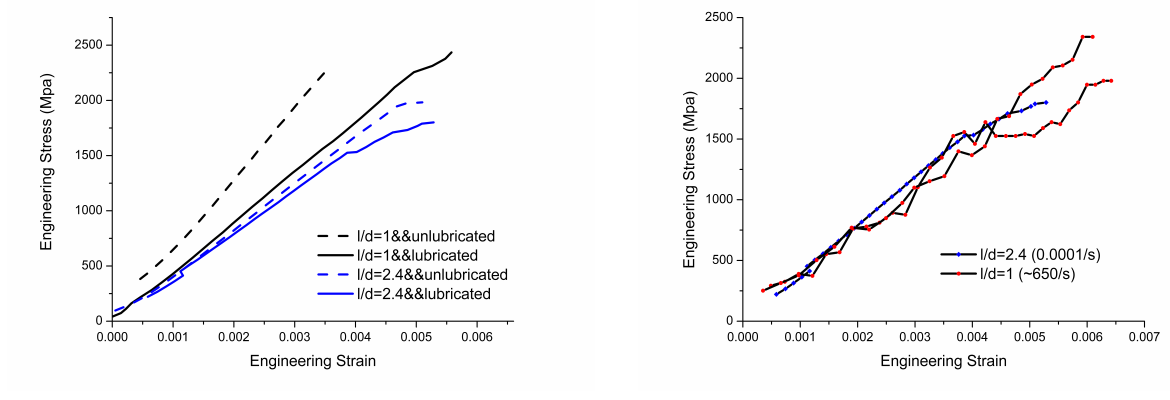
## RESULTS AND DISCUSSION

Fig. 1 illustrates the representative engineering stress-strain curves for alumina. The difference of response between lubricated and unlubricated specimens with higher aspect ratio ($l/d$ = 2.4) was less significant, compared to that of specimens with lower aspect ratio ($l/d$ = 1) (see Fig. 1(a)). This implies that the shorter specimen is more sensitive to lubrication as suggested by Eq. (1). A higher aspect ratio (such as 2.4) is suggested for uniaxial compression experiment under quasi-static rates; suitable lubricants are also needed to reduce the frictional effects.

It was found that no obvious strain rate dependency of alumina at the strain rates ranging from quasi-static up to 650 $s^{-1}$ (Fig. 1(b)). A stress drop occurs at the strain of ~0.004 for both quasi-static and dynamic compression loading.

[a)] Corresponding author. Email: peifeng.li@ntu.edu.sg.

This is probably due to the instability caused by the intersection of the strain localisation with the sides of the specimen. Therefore, the elastic property can't be well-represented beyond this region.




**(a)** **(b)**

**Fig.1 (a) Representative stress versus strain curves at quasi-static compression rates, and (b) comparison of measured stress-strain curves between quasi-static and dynamic compressions.**

## CONCLUSIONS

The behaviour of alumina under uniaxial compressive loads was measured at the strain rates of ~0.0001 and ~650 $s^{-1}$. The behaviour is found to be influenced by both lubrication and aspect ratio. Presence of lubricants on both sides of specimen influences the fracture strain and shorter specimen is more susceptible to friction. No obvious strain rate sensitivity was found in alumina within the tested strain rate range. This may promote our motivation to further study the elastic properties of brittle materials under dynamic conditions.

## References


[1] Field JE, Walley SM, Proud WG, Goldrein HT, Siviour CR(2004) Review of experimental techniques for high rate deformation and shock studies. Int J Impact Eng 30(7):725-775.

[2] Nemat-Nasser S(2000) High strain rate tension and compression testing, In: Kuhn H, Medlin D (eds) ASM handbook, vol 8: mechanical testing and evaluation. ASM International, Materials Park, OH, pp 429-446.

[3] Hall IW, Guden M(2003) Split Hopkinson pressure bar compression testing of an aluminum alloy: effect of lubricant type. J Mater Sci Lett 22(21):1533-1535.

[4] Siebel E(1923) Grundlagen zur berechnung des kraft- und arbeitsbedarf beim schmieden und walzen. Stahl und Eisen 43:1295-1298.