# Investigation of the strain-rate sensitivity of two alumina ceramics thanks to shockless plate-impact spalling tests

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**Abstract.** The present work investigates the tensile behaviour of two alumina ceramics based on shockless plate-impact spalling test. Targets made of a buffer plate as front face and ceramic plate as backing are impacted by metallic wavy-machined flyer plate allowing the wave front to be smoothed to obtain a strain-rate ranging from 9,000 to 30,000 $s^{-1}$. Tests are instrumented with laser interferometry using 1 or 2 optical heads making it possible to measure simultaneously the particle velocities on a point of the buffer rear face and/or the ceramic rear face. Based on these experimental data, the applied load to the ceramic and its spall strength are obtained. Finally the strain-rate sensitivity of two alumina ceramics is deduced.

## Introduction

Ceramic materials are commonly used as protective materials in armour solutions. However, during an impact, an intense fragmentation develops within the ceramic tile due to high-strain rate tensile loadings. This damage process needs to be investigated and taken into account in a numerical simulation of impact. The spalling technique based on planar plate-impact test constitutes a convenient way to explore the tensile strength of brittle materials. In such test, the interaction of release waves coming from both flyer and target rear faces generates an intense tensile stress leading to the initiation of tensile damage and dynamic fracture. The so-called spall strength (tensile strength) can be deduced by using the Novikov's formula [1]:

$$\sigma_{spall} = \frac{1}{2}\rho C_L \Delta V_{pb} \quad , \tag{1}$$

where $\rho$ and $C_L$ are the density and the longitudinal wave speed of the tested material and $\Delta V_{pb}$ is the pullback velocity defined as the difference between the peak velocity to the velocity at rebound measured on the sample rear free surface. However, during a planar impact experiment, the shock loading induces a discontinuity of stress that leads to non-homogeneous stresses and uncontrolled strain rates in the spall region [2-3]. To overcome this limitation, the specimen needs to be slowly loaded by a triangular pulse. To do so, wavy-machined flyer plate impacting a two-layer target (buffer plate bounded to the ceramic plate) can be used. This technique developed in [3] is used in the present work.

## Experimental method

The dynamic testing facility used for the plate-impact tests is a 12 meters-long multi-calibre single stage gas gun installed in 3SR Laboratory (Fig. 1a). In this study, the 80 mm calibre was used to perform the experiments. The striker mass (sabot and flyer plate) of about 400 g is accelerated to an impact speed ranging from 200 to 450 m/s. The ballistic chamber is vacuumed down to 15-25 mbar in order to prevent the formation of a overpressure wave in front of the projectile due to the presence of encapsulated air. Two optical barriers are placed at the barrel exit end to provide an accurate measurement of the projectile velocity at impact. The buffer material is stuck to the ceramic front face. A foam layer is placed between the ceramic and its support in order to ensure a full impedance mismatch. The support is oriented using three elastic fixations to provide an accurate angular adjustment of the target. A Photon Doppler Velocimetry (PDV) system is used as the principal diagnostic system to record the particle velocity on the target rear face. The detector generates a signal that is post-processed using a sliding Fourier transform method of analysis thanks to the analysis code WAVE (WAves data processing for photonic Doppler VElocimetry) developed by CEA DAM Gramat, DEA, STEX and LRME. By recording the beat frequency over time, a complete velocity history of the free surface is obtained. More information is provided in [3].

A specific procedure was set to identify the strain-rate corresponding to the ceramic tensile failure. It consists in simulating the experiment by considering the loading applied to the ceramic. To do so, the velocity at buffer backside is measured by using a second optical probe in addition to the probe directed to the rear face of the ceramic target (Figs. 1b, 1c). This particle velocity provides the loading pulse transferred to the ceramic according to the following equation:

$$\sigma_{transmitted} = \frac{\rho C_L \times \rho_b C_b}{\rho C_L + \rho_b C_b} V_b \quad , \tag{2}$$

where $\rho C_L$ is the acoustic impedance of the target, $\rho_b C_b$ is the acoustic impedance of the buffer and $V_b$ is the buffer free-surface velocity. This pulse is used as input data in the numerical simulation.

Flyer plate geometries and nominal spalling configurations for shockless plate-impact experiments are reported in the Fig. 2. The four flyer-plate geometries are characterized by a flat rear face and a wavy shaped front profile with a height (H) and half-period (P) of 0.125-0.25 mm and 0.5-1 mm, respectively. The nominal impact velocities range from 200 to 450 m/s.

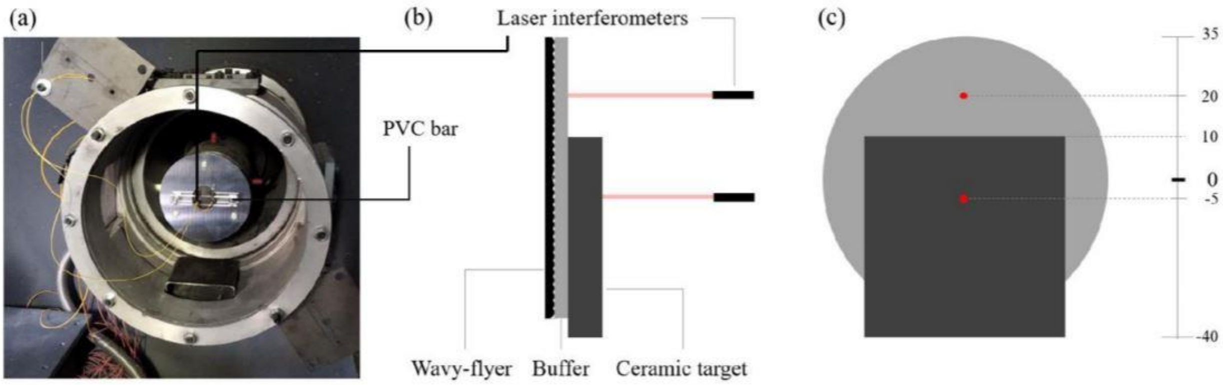
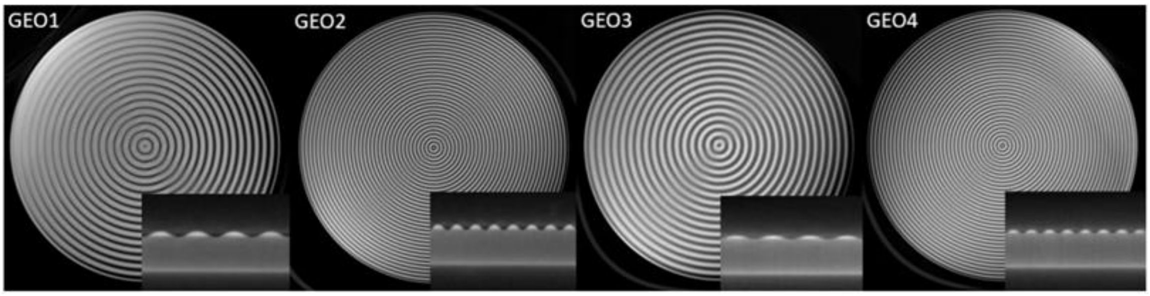



Fig 1. (a) Instrumented rear face of the ceramic target. Schematic showing the 2 laser-probes set-up used to measure simultaneously the loading pulse and the ceramic free-surface velocity. Side view (b) and back view (c) [3].




| Flyer geometry | Profile period (mm) | Profile height (mm) | Nominal impact velocities (m/s) | | |
|---|---|---|---|---|---|
| GEO1 | 1 | 0.25 | 350 | - | - |
| GEO2 | 0.5 | 0.25 | - | 250 | 200 |
| GEO3 | 1 | 0.125 | 350 | - | - |
| GEO4 | 0.5 | 0.125 | 350 | 450 | 450 |

Fig. 2. Flyer plate geometries and nominal configurations for shockless plate-impact experiments [3].

## Conclusion

In the present work a ten of spalling tests were conducted with two alumina ceramics. The spalling tests performed on dense alumina exhibited much higher spall strength values (from 430 MPa to 530 MPa) compared to porous alumina (from 260 to 360 MPa). A specific procedure was set to calculate the strain-rate associated to each test. The estimated strain-rate is based on an elastic numerical simulation of each test which provides the expected location of spall failure and the strain-rate at a stress level equal to the spall strength. Numerical simulations with DFH (Denoual-Forquin-Hild) damage model were also conducted and are shown to be an alternative method to estimate the strain-rate and the position of fracture plane responsible to the rebound in the velocity profile. Finally, this study validates the use of shock-less plate impact spalling tests to identify the strain-rate sensitivity of ceramic tensile strength.

## References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