# NUMERICAL MODELING OF SPALLING PHENOMENON ON ALUMINA BY DISCRETE ELEMENT METHOD

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**Abstract**
The numerical Discrete Element Method (DEM) approach has already proven its legitimacy to represent the behaviour of brittle or quasi-brittle materials such as ceramics at quasi-static regime. The present study investigates the DEM approach in reproducing the dynamic behaviour of an AL23 ceramic under dynamic spalling tests. Elastic microscopic parameters of the DEM model are calibrated using quasi-static uniaxial tensile tests in order to match the macroscopic elastic behaviour of an AL23 ceramic. The DEM model is then used to simulate the stress waves propagation, interactions and fracture mechanisms generated during spalling damage tests. Rear face velocity profiles have been measured and compared to the numerical results. The strain-rate sensitivity of the spalling stress of AL23 ceramic has been observed experimentally. The anisotropic DFH (Denoual-Forquin-Hild) damage model is implemented in DEM to take into account the strain rate sensitivity. Several methods to manage anisotropy in DEM are tested.

## 1 Introduction

Given the complexity of cracks initiation and propagation, the numerical prediction of quasi-static or dynamic behaviour of brittle materials is an open area of research. The Discrete Element Method (DEM) approach may be an alternative to respond to these issues, which have been hardly treated by continuum mechanics or analytical methods. DEM approach was originally used to model fracture mechanisms in granular media like rocks, concrete, hail, ice or metallic powder. This approach has been recently extended to continuous and homogeneous media. The model is investigated in dynamic fragmentation because the DEM model deals naturally with crack initiation and propagation. As highlighted, different scientific locks still resist. The understanding of dynamic fragmentation of brittle materials, especially ceramics, under high strain-rate loading must be improved. The present work focuses on the simulation of spalling damage tests and the strain-rate sensitivity of an alumina subjected to a high strain-rate loading induced by GEPI experiments.

## 2 Results

Continuous medium is represented in DEM by spherical particles connected by cohesive beam managed by the Euler-Bernoulli theory. A calibration step through uniaxial tensile tests is needed to connect the mechanical properties of the discrete elements and bonds to the macroscopic mechanical properties of the material (AL23 alumina). To evaluate the legitimacy of the DEM approach to predict the dynamic behaviour and fracture mechanisms of brittle materials, simulations of GEPI experiments are modeled in DEM. The GEPI mean produces sinusoidal magnetic pressure impulses that generate stress waves in samples in order to highlight shockless spalling damage. Three GEPI experimental shots on AL23 samples have been taken as reference. Spalling phenomenon consists in release stress waves interactions that generates high tensile stress in the sample and results by cracks initiation and propagation, and spall fragments ejection (Figure 1). The rear face velocity signal is captured and prove that spalling has occurred during tests (Figure 2). Parts of the stress waves are imprisoned into the spall and propagate

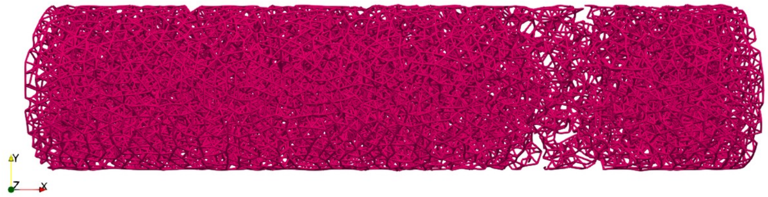

Figure 1: DEM domain after spalling simulation.

between the spalling zone and the rear face of the sample. The DEM simulations of the three GEPI experiments are compared on Figure 2. There is a quite correct correlation between the numerical and the experimental results. At high stress level, the discrepancy on the release phase is attributed to the particular behaviour of the AL23 alumina ceramic : its sensitivity to the strain-rate. As other ceramic like silicon carbide, the strain rate dependence is low under 100 $s^{-1}$ and high above 100 $s^{-1}$. A method to estimate the strain-rate and the associated spalling stress in DEM is proposed. The non- sensitivity to the strain rate of the original DEM model is demonstrated. Hence the DFH (Denoual-Forquin-Hild) anisotropic damage model is implemented in DEM. Then the DEM model becomes strain-rate dependent and follow the experimental evolution. The anisotropy management is DEM is a complex challenge. A geometrical approach is used to transform the anisotropic damage vector from the DFH model into a scalar damage variable that can deteriorate the mechanical properties of the cohesive beams.

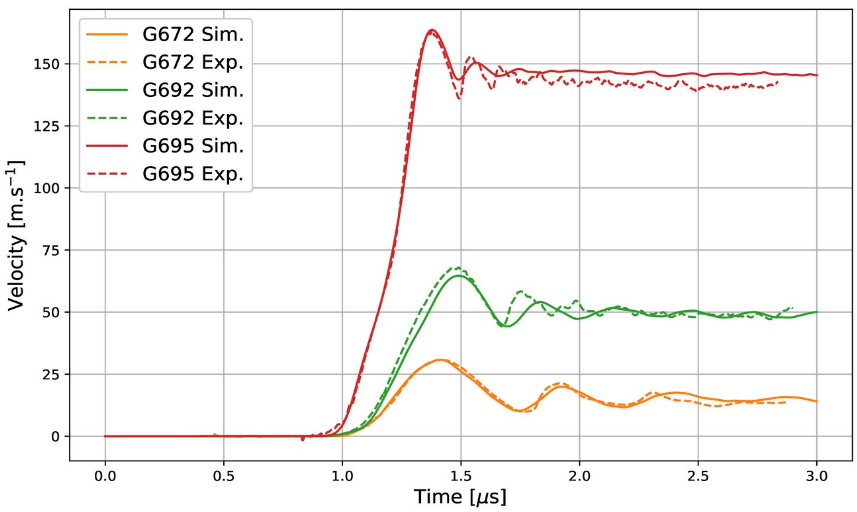


Figure 2 : Experimental and simulated rear face velocity of three different GEPI shots.

## 3 Conclusions

The DEM approach appears to be consistent in modeling the dynamic behaviour and fracture mechanisms of brittle material as the AL23 alumina ceramic. The propagation and interaction of stress waves simulated by DEM are relevant. The strain-rate sensitivity of the ceramic is taken into account by the implementation of the DFH anisotropic damage model. A good correlation is observed between experimental and numerical results. Further works will apply the DEM model to simulate laser shock experiments recently performed on AL23 samples.

## 4 References

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