A testing technique to investigate the dynamic crack propagation in armour ceramic

Numerical analysis through « Rockspall »

Keywords : *ceramics, dynamic behaviour, spalling, crack velocity, dynamic fracture toughness, « Experdyn » platform .*

Academic: Y. Duplan[1*], P. Forquin[1] (Pr.), B. Lukić[1] (Dr.), D. Saletti[1] (Dr.)

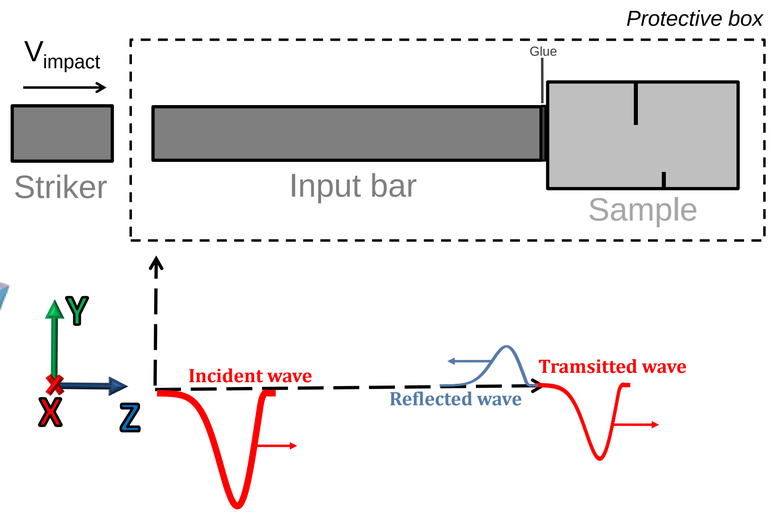
[1] Univ. Grenoble Alpes, CNRS, Grenoble INP, 3SR laboratory, 38100 Grenoble, France
[*] yannick.duplan@3sr-grenoble.fr

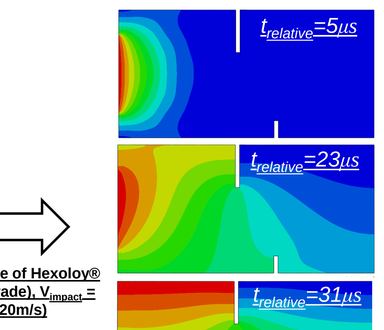
Industrial: M. Graveleau[2] (Dr.), F. Barthélemy[3]

[2] Saint-Gobain CREE, 84300 Cavaillon, France
[3] DGA TT, 18021 Bourges, France

Abstract: Ceramic materials are numerically studied to understand their **fracturing behaviour upon dynamic conditions and impact loadings**. During a ballistic impact of a projectile against a ceramic armour system, an intense **fragmentation** composed of numerous oriented cracks, develops in the target. It is the reason why the **conditions of crack initiation, propagation and arrest** in these materials need to be investigated. In the present work, a dynamic testing configuration has been developed in order to characterise the **dynamic fracture toughness ($K_{I,d}$)**, considering a single crack that propagates from the specimen notch tip. The "Rockspall" testing technique, which employs a **two-notch specimen** loaded in a spalling experiment, was used. Thanks to the reflection of a compression wave into a tensile load from the sample free-end, a **single dynamic crack is triggered**. The sample geometry is optimised by means of a series of FE numerical simulations involving an anisotropic damage model.

Rockspall: *Rock*ing by *spall*ing





Rocking effect (induced transversal displacement) → *Increase of tensile stress on the small notch*

Axial stress field → *Wave not unidirectional*

Crack propagation (SDV8 variable) → Single cracking occurs when the average flexural stress σ_w is reached

Goals

- NUMERICAL
  - To determine the optimal geometry of the sample
  - To predict the crack velocity and to validate the measurmeent of $K_{I,d}$
- EXPERIMENTAL
  - To perform these experiments on ceramics
  - To compare experimental results with numerical predictions

Damage model for brittle materials: DFH (Denoual-Forquin-Hild)

[Denoual and Hild, 2000; Forquin and Hild, 2010]

- **Principle:** Each defect (*e.g.* pores) has an initiation stress above which a crack can propagate. When one of them initiates and propagates, a volume of relaxation stress called obscuration volume V_0 is generated around the crack, preventing the triggering of critical defects in its vicinity.

DAMAGE PARAMETER

$$D = P_{obscuration} = 1 - \exp\left(-\int_0^T \frac{\partial \lambda_t}{\partial t}.V_0(T-t).dt\right)$$

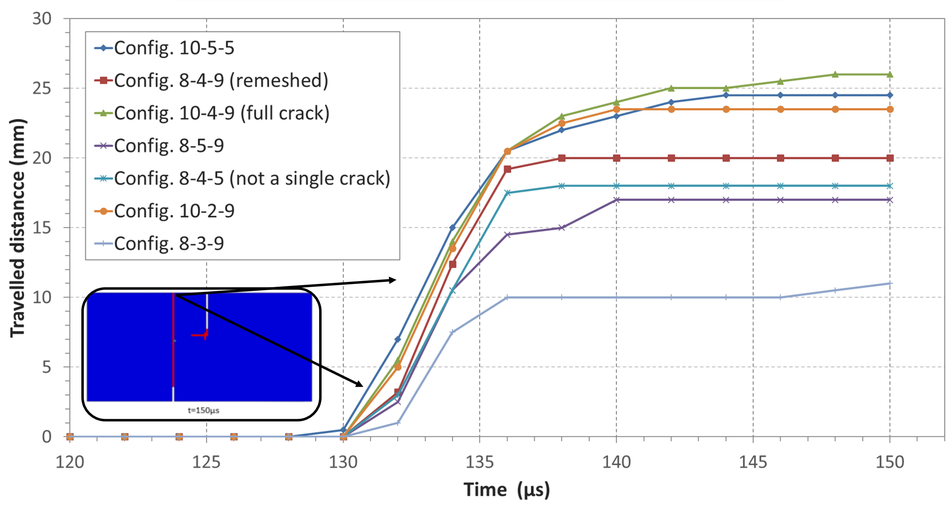
CRACK PROPAGATION and TOUGHNENING

$$v_{crack} = k.C_0 \quad ; \quad V_0(T-t) = S[v_{crack}(T-t)]^n$$

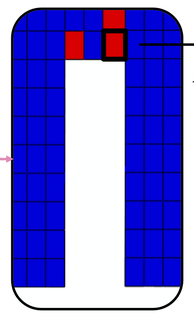
Optimisation of the geometry – Predictions

- Finite Element Analysis using ABAQUS\Explicit.

Evolution of the crack distance from the small notch tip



Crack distance for different configurations: 10-4-9 is found to be the best



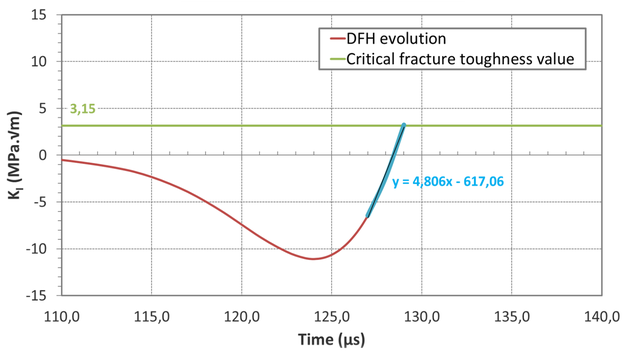
K_I calculus (until cracking) with displacement extrapolation method, based on Crack Opening Displacement (COD)

- Different configurations tested:
  - Big notch length
  - Small notch length
  - Distance between notches

E.g. 10-4-9 = 10-mm big notch, 4-mm small notch, 9-mm between notches

- Get the approximative fracture toughness rate $\dot{K}_I$:

Evolution of fracture toughness

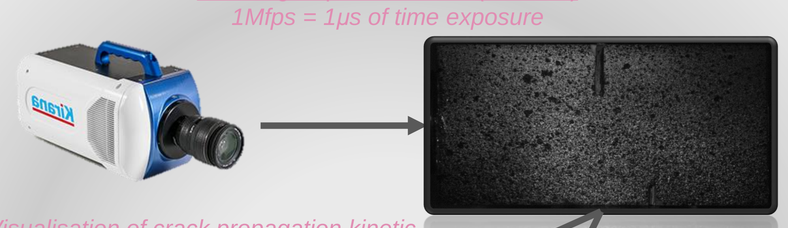


$\dot{K}_{I,nominal} \sim 4.81 \mathrm{MPa}.m^{1/2}.\mu s^{-1}$

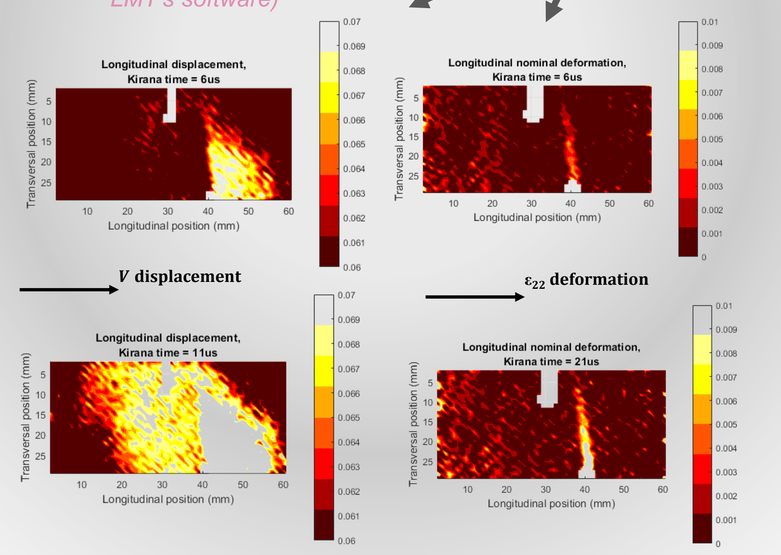
First experimental results

Example on a SiC ceramic (Forceram®), impacted at 4.58m/s.

Ultra High Speed Camera (Kirana®)
1Mfps = 1µs of time exposure



Visualisation of crack propagation kinetic by Digital Image Correlation (CorreliQ4 LMT's software)



CONCLUSION

- Finite Element modelling with DFH model allows to **compute crack phenomenon in dynamic**, here illustrated in **single fragmentation**.
- Rockspall tests are used to investigate single crack propagation and so to **characterise dynamic resistance**, where **impact velocities are predicted** thanks to numerical simulations.
- Further work: To compare numerical and experimental crack velocities.

References :

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P. Forquin, F. Hild. *A probabilistic damage model of the dynamic fragmentation process in brittle materials*, Advances in Applied Mechanics Adv. in Appl. Mech. 44, 1-72 (2010).

Laboratoire Sols, Solides, Structures – Risques
Domaine Universitaire - BP53 / 1270 rue de la piscine - 38100 Grenoble
www.3sr-grenoble.fr
contact: 04 76 82 70 87 / direction@3sr-grenoble.fr