Characterization of the dynamic behavior of ceramics using High-Pulsed Power Technologies

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Since the 60s, ceramic materials like silicon carbide or alumina are commonly used in armor systems for the foot-soldier protection or military vehicles [1]. Indeed, they present interesting mechanical and physical properties like a low density combined with an exceptional hardness and compressive strength. Thus, for the same level of protection, the use of ceramic materials allows a considerably weight benefit in comparison with laminated steel plates armors. However, besides their interesting properties and their capabilities in shattering projectiles, ceramics present a brittle behavior under tensile loading leading to an intense fragmentation during impact. One way to limit this drawback consists in associating the ceramic plate with a back layer made of ductile materials. The evaluation of the capability of a ceramic in stopping projectiles is generally determined by performing a series of ballistic tests in representative configurations. However, using this technique, the mechanisms governing the performance of a ceramic cannot be understood. Moreover, significant differences of performance are observed even in a same family of ceramic. In order to understand the links between the microscopic characteristics of ceramics and their macroscopic behavior, characterization tests are needed on different kind of ceramics and through different dynamic loadings.

During the first microseconds after impact, the ceramic is subjected to a high compressive stress state which can cause fracture and plasticity in the ceramic when the compressive stress approaches the Hugoniot Elastic Limit of the material [2]. In order to characterize a ceramic under dynamic compressive loading, plate impact experiments are generally performed. However, using this kind of experiments, a large number of experiments is needed if one wants to reconstruct the shock response of a material. Since the beginning of the 21st century, high-pulsed power technologies appear to be a very interesting way for the dynamic characterization of materials. Indeed, they allow applying a ramp loading spread over few hundreds of nanoseconds with a peak pressure greater than 20 GPa. In the CEA Gramat, the GEPI device, based on the strip line concept, generates a current up to 3.3 MA with a rise time of 500 ns [3]. Thanks to the strip line geometry, two specimens can be tested during the same experiment (one specimen on each electrode). This configuration allows using the "lagrangian analysis" method. This method, by integrating the equations of conservation between two velocity signals, allows an accurate identification of the compressive behaviour of the material [4]. This kind of

experiments has been applied on different silicon carbide grades. Significant differences have been observed between ceramics, particularly in terms of Hugoniot Elastic Limit of the material.
During a ballistic impact, the ceramic is also subjected to a tensile loading causing its fragmentation. In order to characterize the tensile strength of ceramics, spalling tests are generally performed. Whereas spalling tests performed by plate impact are most common, the use of High-Pulsed Power generators presents numerous advantages. Thanks to the ramp loading applied to the specimen, the strain-rate can be accurately determined every time during the test and everywhere in the specimen. By varying the amplitude of the loading pulse, a strong strain-rate sensitivity of the tensile resistance is observed for each ceramic. Another great advantage of this technique is the capability in recovering damaged specimen. Contrary to plate impact experiments, the use of the GEPI machine does not need any additional system to recover damaged specimens [5]. After spalling tests performed at relatively low strain-rate (about 5000 s^{-1}), damaged but unbroken specimens can be recovered. These specimens then give, after microscopic analysis, unique insight about the fragmentation process in brittle materials. This spalling technique has been applied to characterize the dynamic behaviour of an alumina [5] and two silicon carbides [6].

References

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