Ceramic armour materials for ballistic applications: performance and future improvements

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Abstract: *Ceramic materials, broadly defined as inorganic nonmetallic solids, have been used successfully in ballistic protection systems since the 1960s.*

It is the combination of physical and mechanical properties that qualifies advanced ceramics for personal, vehicle and helicopter components, standing out their low density, superior hardness, favorable elastic constant, and high compressive strength. However, no ceramic material exhibits, by itself the characteristics required to withstand the combination of mechanical stress from a ballistic event. Thus, ceramic armour systems consist of a monolithic or composite ceramic covered by a baking material, which could be a metallic alloy and/or a polymer material. If the baking layer will provides the ductility and the structural integrity and spreads the forces resulting from the impact ballistic of a projectile over a large area, one can ask, on balance, which is the best property for the ballistic behavior of *a* ceramic material*?*

Unfortunately one can't, actually, correlate the ballistic performance to a single property or characteristic. This is due to the dynamic nature of the event (nano or microseconds). Thus, it is always necessary to execute ballistic tests to assess the system efficiency. Nevertheless, the most important properties, Table 1, are directly affected by the ceramic material microstructure in the form of grain size, crystalline phase, phase transitions, and porosity. Since the microstructure depends on the processing route, ceramic processing methods are decisive factors in developing the ballistic ceramic market.

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Table 1. Material properties and the respective ballistic performance

Property	*Ballistic effect*
Density	*Weight system*
Hardness	*Damage to the projectile*
Young's Modulus	*Propagation of stress waves*
Mechanical strength	*Resistance to multiple impacts*
Fracture toughness	*Resistance to impacts / durability*
Fracture mode	*Energy absorption*

In addition, ceramic armour systems are designed based on the requirements of performance, weight, application and manufacturing ability.

*This course, of introductory character, aims to provide expertise on structure / properties / processing / performance of ceramics materials emphasizing the technological aspects that should govern its application in ballistic protection purposes. Moreover, knowledge of the different materials used in engineering is one of the main specific skills required for sustain practicing engineers, since "*All engineering depends on the materials*:* the better they are, the better the engineering works. So all engineering are, or have to be, to some degree, *Engineering* Materials*", William F. Smith, Principles of Materials Science and Engineering, McGraw-Hill.*

With an increase in the weapon penetration capability, there will be a need for new devices to be developed producing the desired level of protection for their combat role. The evolution of the defense industry must progresses alongside the arms industry!

Future trends to improve ceramics ballistic performance will also be addressed via different solutions. One is through Materials Science, where understanding how the projectile interacts with the ceramic material informs the design of novel ceramic microstructures. Recent scientific research works will be addressed, such as, i) the preparation of high strength ceramics by reducing the grain size to nanometer scale; ii) the architecture of functionally graded armour materials and; iii) the reinforced ceramic structures with carbon nanotubes and graphene. Finally, expected evolutionary and revolutionary developments are sketched for the lightest and the hardest ballistic ceramic material, the B4C, based on studies conducted at University of Coimbra.