Nano ceramics for armor

Currently, bullet-proof vests (soft or flexible composite armor used for body protection) are basically made from high stiffness and toughness, woven or laminated, polymeric fibers stacked in a number of layers. Upon impact of the striking bullet, the fabric material absorbs the energy by stretching of the fibers and the stiff fibers ensure that the load is dispersed over a large area throughout the material. This process slows down the bullet and ultimately stops it from penetrating the body.

In case of polymer matrix composites (PMCs), the ability of a fiber to deform is severely restricted due to the presence of surrounding resin, and therefore, the energy absorption capacity is reduced. The main failure mechanisms in PMCs under ballistic impact are straining of fiber and its fracture, delamination and shear deformation in the resin matrix.

To provide greater protection against blunt trauma and higher velocity ammunition than can be provided by a stand-alone soft ballistic vest, hard body armor has been developed. It includes a rigid facing comprising ceramic inserts, steel or titanium panels and a ballistic fabric backing. In hard armor with ceramic inserts, the kinetic energy of the projectile is absorbed and dissipated in localized shattering of this ceramic tile and blunting of the bullet material during its impact on the hard ceramic.

Armor ceramics are critical for weight reduction in current and future military and civilian applications, including personnel protection. The realization of the full potential of armor ceramics requires a basic understanding of how the structure of armor-ceramic materials, at several length scales, affects the inherent ballistic performance and the variability of ballistic performance among nominally identical components. Key aspects of ceramic armor materials at the atomic, nano, micro, and macro scales that are significant to ceramic armor performance must be identified and understood.

Significant research has been conducted to develop fully dense ceramic materials for armor applications, since porosity has been shown to reduce ballistic performance. The effect of grain size on the strength and hardness of ceramics materials in static and quasi-static testing has been known for many years. Most current, commercial armor ceramics sacrifice finer grain size to minimize porosity, resulting in grain sizes significantly larger than 1 μm.

Toughness can also be improved by decreasing grain size. With the latter, the strength of dislocation pile-ups at the grain boundary increases, which results in a change in the fracture mode from transgranular to intergranular fracture. The latter results in a grater energy requirement for crack propagation and therefore results in higher toughness. When the mean grain size is below 100 nm, i.e. the ceramics are nanocrystalline, they can deform plastically and extensively by grain boundary sliding. This 'superplastic deformation' is in sharp contrast to the usual brittle behaviour associated with commercial ceramics. Nanosized zirconia is an example of a superplastic ceramics with high toughness (see "Development of Nano Zirconia Toughened Alumina for Ceramic Armor Applications").

The U.S. Army Research Laboratory dedicated a 5-year program to advanced metals and ceramics for armor and anti-armor applications ("Advanced Metals and Ceramics for Armor and Anti-Armor Applications. High-Fidelity Design and Processing of Advanced Armor Ceramics"; pdf). The two major objectives were to 1) characterize the behavior of

nanoceramics in ballistic impact and b) demonstrate nanoceramic fabrication techniques that are scalable and cost-effective.

Other research on the nanofabrication of armor takes a biomimetic approach. Seashells, for instance, are natural armor materials. The need for toughness arises because aquatic organisms are subject to fluctuating forces and impacts during motion or through interaction with a moving environment. Nacre (mother-of-pearl), the pearly internal layer of many mollusc shells, is the best example of a natural armor material that exhibits structural robustness, despite the brittle nature of their ceramic constituents. Research has revealed the toughening secrets in nacre: rotation and deformation of aragonite nanograins absorb energy in the deformation of nacre. The aragonite nanograins in nacre are not brittle but deformable. These findings may lead to the development of ultra-tough nanocomposites, for instance for armor material, by realizing the rotation mechanism (read more: "Nature's bottom-up nanofabrication of armor").

Carbon nanotubes (CNTs) are being considered as a reinforcing material to enhance the mechanical properties of ceramics, particularly by fracture toughness, which is likely to improve their resistance against multiple hits by bullets. Recent studies have shown that incorporation of CNTs in ceramics like alumina and silicon carbide can have a strong influence on the microstructure, fracture mode and mechanical properties. A significant improvement of up to 94% in fracture toughness was observed when 4 vol. % of CNTs are added to alumina

MECHANICAL CHARACTERISTICS OF NANOCERAMIC/METAL LAMINATED COMPOSITE IN THE IMPACT TEST

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Conference: Les Journées Spécialisées Réfractaires, At Mons

ABSTRACT Lightweight laminated composites containing a ceramic front layer and a backing layer were widely used in vehicles and also can be used as refractory materials for using in linings for furnaces, kilns, incinerators and reactors. In this study, by adding SiC nano-scale particles on the Al2O3 matrix and applying optimum sintering conditions, ceramic impact performance was improved. A number of target samples with two different types of front layers were produced. The diameter of the base of failure cone after impact tests was measured. The results of the impact tests on the samples were compared and analyzed. The results indicate that measured diameter of the base of failure cone for nanoceramic samples is more than raw specimen and this is related to increasing of the angle of failure cone. Introduction A lightweight laminated composite of ceramic/metal provides suitable protection against high-speed impact. Changes in the properties and dimensions of layers will change the response of the target. Woodward [1] provided an analytical model for the mechanism of impact and projectile penetration into a ceramic/aluminum composite target. Roger [2] developed Woodward's model and presented the mechanisms of projectile penetration into the ceramic target. Another analytical model was presented by Zaera and Sanchez-Galvez [3] for analysis of projectile penetration into tile ceramic. Here, the behavior of the metallic backing layer was modeled. Niihara [4] was uniformly distributed nano-particles inside the matrix of alumina. Asadi et al. [5] have observed that with the addition of SiC particles, the ceramic fracture mode changed from inter granular to trans granular, and this change in fracture mode improves the strength and the fracture toughness of the ceramic. In order to improve the mechanical properties, some silicon carbide nano particles and a small amount of magnesium oxide

nano particles are utilized. Experimental Work Two series of lightweight ceramic/metal composite targets with Al backing layer were produced and tested under impact by metallic projectile. The amount of bulge of the backing layer was measured for all of the samples. The alumina powder used in this study has the grain size of 3 microns. The SiC and MgO particles have grain size of below 100 nanometers. The nanocomposite tiles were prepared by a hot pressing process. Alumina powder and silicon carbide were mixed with volume percentage of 10%. Nanocomposite tile samples with dimensions of 120×120×12 mm were formed by hydraulic press in the pressure of 30 bars. Samples were sintered by a hot press machine with a graphite die under pressure of 30 MPa for 2 hours. The resulting samples were grinded and polished for subsequent tests. Physical and mechanical properties including the relative density, hardness, strength, elasticity modulus, and fracture toughness measured by standard methods and results were used to select optimum sintering conditions. Optimum condition is defined as the maximum energy distribution coefficient of samples as shown by Sadough Vanini et al. [5]. The energy distribution coefficient is calculated using Eq. (1) as shown by McCauley et al. [6]:

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