PROCESSING MULTI-PHASE CERAMIC COMPOSITES FOR VEHICULAR SURVIVABILITY
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In the past, the most capable armor was heavy and developed for main battle tanks weighing 50 tons or more. The increasingly changing state of global politics requires rapid deployment of a military force anywhere in the world. Rapid deployment dictates that the best armor be available for lightweight military vehicles. The urgency to deploy Army’s Future Combat System has challenged the armor materials community to employ non-traditional materials to meet operational space, weight and logistic constraints.

Monolithic ceramics such as alumina (Al₂O₃), boron carbide (B₄C), silicon carbide (SiC), tungsten carbide (WC) and titanium diboride (TiB₂), incorporated as armor system components, effectively defeat kinetic energy threats. However, advancing monolithic ceramics through efforts in two, parallel but related areas of investigation: encapsulation in metal and the creation of multi-phase ceramic composites provide the opportunity to improve ballistic performance while saving weight and cost. Insights gained from encapsulation and multi-phase ceramic studies form the basis for the current direction in processing multi-phase ceramic composites for vehicular survivability.

For some time, it has been known that Al₂O₃ based armor systems are simple but effective. Al₂O₃ is a sintered, rather than hot-pressed, component of armor, and because of its large demand by the Al industry [EMH Vol. 4, 1991, p.50], is inexpensive as compared to B₄C, SiC and TiB₂. Al₂O₃, no matter the type, resists penetration linearly as tile thickness increases (0 to 30 mm) [Strassburger et al., 1995]. Its mechanical properties can be improved by the addition of a second phase of small, dispersed, non-equiaxed TiB₂ particles [Liu and Ownby, 1991], however the TiB₂ is high cost, which stems from its energy intensive processing via carbothermal reduction [EMH Vol. 4, 1991, p.48]. Fuel costs are high to reach the temperatures required for TiB₂ production. An alternate synthesis route is via a particular form of combustion termed self-propagating-high-temperature-synthesis (SHS) [Merzhanov, 1990, pp. 1-3]. SHS is an instantaneous event rather than a long-term, high- temperature reaction as is carbothermal reduction. SHS thereby eliminates high fuel costs, and also incidentally increases the purity of the resulting powders. Logan [Ph.D. Thesis, 1992] is able to produce not only TiB₂ powders by SHS, but also the composite Al₂O₃/TiB₂ powder.

The Al₂O₃/TiB₂ composite system, both SHS and mixtures of Al₂O₃ with carbothermically produced TiB₂, showed early favorable ballistic results [Abfalter et al., 1992], and were used to evaluate processing challenges to control the distribution of the two ceramic phases. As with other advanced ceramics, however, difficulties in processing Al₂O₃/TiB₂ arise from the inability to reproduce specimens with consistent microstructure and properties [Lange, 1989], but colloidal processing can improve processing reliability and therefore provides more consistent ceramics [Lange et al., 1990]. Franks [Masters Thesis, 2001] effectively predicts the coagulating behavior of mixtures of Al₂O₃ and TiB₂, but the SHS {Al₂O₃/TiB₂} is insensitive to colloidal processing. The insensitivity of the SHS {Al₂O₃/TiB₂} is a reflection of SHS powder being a composite in each individual grain rather than a mixture of two distinct ceramic powders [Wilson, 2001].
Further hot pressing studies of simple electrostatic dispersed mixtures of Al₂O₃ and TiB₂ allowed formation of controlled structures ranging from uniform agglomerates of Al₂O₃ clusters in TiB₂ to fully dispersed Al₂O₃ in TiB₂. The ballistic performance of a 70:30 Al₂O₃-TiB₂ clustered composite performed better than the uniformly dispersed composite.

Again for some time it has been known that encapsulation of ceramics in metal impedes failure during a ballistic event. It is likely that encapsulation imposes compressive stresses, thus extending penetration resistance. Therefore, if compressive stresses can be induced in the ceramic without encapsulation (saving weight), it is expected that the ceramic alone will impede failure in a ballistic event. Although Al₂O₃ and TiB₂ clustered, inherent compressive stresses do not form as Al₂O₃ and TiB₂ have similar coefficients of thermal expansion (CTE).

This paper will present exploratory results and future strategy of introducing self-confinement in a ceramic via macro-design of thermal expansion (CTE) mismatches in the microstructure to enhance the ballistic performance of the ceramic.

The CTE mismatch between AIN and TiB₂ is high. An AIN-clustered TiB₂ matrix composite will induce significant internal confining stresses that can be tailored according to the ratio of the components and their distribution. Preliminary hot pressing of this composite resulted in a micro cracked material. The next stage of this work will include microstructure design modeling, failure analysis and ballistics. Future study could incorporate electromagnetic signature design by geometric distribution of the conductive TiB₂ phase in the dielectric AIN phase.


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