

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 (Al_2O_3), boron carbide (B_4C), silicon carbide (SiC), tungsten carbide (WC) and titanium diboride (TiB_2), 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 Al_2O_3 based armor systems are simple but effective. Al_2O_3 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 B_4C , SiC and TiB_2 . Al_2O_3 , 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 TiB_2 particles [Liu and Ownby, 1991], however the TiB_2 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 TiB_2 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 carbothermic 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 TiB_2 powders by SHS, but also the composite $\text{Al}_2\text{O}_3/\text{TiB}_2$ powder.

The $\text{Al}_2\text{O}_3/\text{TiB}_2$ composite system, both SHS and mixtures of Al_2O_3 with carbothermically produced TiB_2 , 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 $\text{Al}_2\text{O}_3/\text{TiB}_2$ 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 Al_2O_3 and TiB_2 , but the SHS $\{\text{Al}_2\text{O}_3/\text{TiB}_2\}$ is insensitive to colloidal processing. The insensitivity of the SHS $\{\text{Al}_2\text{O}_3/\text{TiB}_2\}$ is a reflection of SHS powder being a composite in each individual grain rather than a mixture of two distinct ceramic powders [Wilson, 2001].

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Further hot pressing studies of simple electrostatic dispersed mixtures of Al_2O_3 and TiB_2 allowed formation of controlled structures ranging from uniform agglomerates of Al_2O_3 clusters in TiB_2 to fully dispersed Al_2O_3 in TiB_2 . The ballistic performance of a 70:30 Al_2O_3 - TiB_2 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 Al_2O_3 and TiB_2 clustered, inherent compressive stresses do not form as Al_2O_3 and TiB_2 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 AlN and TiB_2 is high. An AlN -clustered TiB_2 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 TiB_2 phase in the dielectric AlN phase.

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