Unlocking the True Potential of the World’s Strongest Armor Material
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Boron carbide is one of the hardest known materials (surpassed by only diamond and cubic boron nitride) and yet it weighs even less than a lightweight metal such as aluminum (boron carbide density $\approx 2.5$ g/cm$^3$, aluminum density $\approx 2.7$ g/cm$^3$). Boron carbide has multiple uses, ranging from nuclear radiation shielding to wear-resistant nozzles. Due to its low density and exceptionally high hardness (resistance to penetration), boron carbide is especially appealing for use as lightweight body armor and vehicle armor. Boron carbide armor offers excellent protection against bullets, blades, and other threats while weighing almost 30% less than popular silicon carbide armor of similar design (silicon carbide density $\approx 3.2$ g/cm$^3$).

Boron carbide is indeed a highly effective armor material, but it is not the best choice for all armor designs. Studies have revealed that regions of boron carbide which are exposed to high pressure experience a transformation in which the molecular structure of the material breaks down through a process known as amorphization. A map of amorphized material on an indented surface is shown in Fig. 1. The amorphized (disordered) material is weaker than the surrounding untransformed (ordered) material and limits the effectiveness of boron carbide armor against high-velocity threats which generate enough pressure upon impact to cause amorphization.

In this research, a sharpened diamond with a pyramid-shaped tip is used to test a material’s hardness (resistance to penetration) by indenting its surface at different loading rates (slowly applied force versus rapidly applied force). In these tests, most materials perform better at faster loading rates (that is, they are more resistant to penetration when a load is applied quickly). In contrast, our tests show that boron carbide is weaker (less capable of resisting penetration) at faster loading rates. This may be due to the weakening effect of amorphization becoming more severe at higher loading rates, which further reduces the ability of boron carbide armor to protect against high-velocity ballistic impacts.

Much is still unknown about the amorphization process in boron carbide, including its dependence upon loading rate, the precise level of pressure required to cause amorphization, and also the size and shape of the affected zone beneath an indentation or impact site. The goal of my research is to gain a better understanding of amorphization in boron carbide by studying the size and shape of the transformed regions surrounding indentations and impact sites. A variety of penetrator shapes, impact speeds, and impact loads are used to generate the amorphized zones of interest, as shown in Fig. 2. By combining these results with existing knowledge, it will be possible to generate more accurate physics-based computer simulations of the amorphization process. This knowledge will serve as the foundation for theories on how to minimize or eliminate the weakening effects of amorphization, thus bringing boron carbide – the hardest lightweight armor material available – closer to being the ideal armor material for defense against all physical threats.