2D MXenes-derived TiB_2 formation in B_4C at high temperatures

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Two-dimensional (2D) MXenes are nanometer-thick sheets of transition metal carbides, nitrides, or carbonitrides with high-temperature capabilities [1,2]. MXenes can be used as nanofillers and functional additives in ceramic hybrids, enhancing sintering and mechanical and electrical properties [3]. In this study, we systematically investigate the incorporation of titanium carbide ($Ti_3C_2T_x$) MXene into micron-sized (~ 6 μm) boron carbide (B_4C) using a one-step electrostatic self-assembly method [2]. We tuned the zeta potential of B_4C and $Ti_3C_2T_x$ MXene solutions, gradually added B_4C into the MXene solution, and prepared green bodies with 1 to 10 vol.% $Ti_3C_2T_x$. We examined MXene phase stability, reactions, and phase transformation in B_4C via direct current spark plasma sintering at 1925 °C with a pressure of 70 MPa in a vacuum. To understand the reaction pathways, we conducted stepwise sintering from 800 °C to 1800 °C in 200 °C increments. X-ray diffraction and scanning electron microscopy results revealed that $Ti_3C_2T_x$ reacts with B_4C at ~ 1200 °C to form TiB_2, with complete conversion at 1800 °C, resulting in a TiB_2-B_4C structure. For samples with 4 vol.% MXene or higher, B_2O_3 formed above 1200 °C due to MXene oxygen terminations and disappeared above 1800 °C. The overall oxygen content in MXene-containing samples was lower than in B_4C sintered without MXene, indicating its reducing nature as a 2D carbide. MXene also acts as a sintering additive, and the relative density was increased by increasing the MXene content, achieving 99% with 10 vol.% MXene. The measured hardness values were 20 ± 1.6 GPa and 41 ± 0.8 GPa for B4C and B4C with 10 vol.% MXene Ti_3C_2 samples, respectively. This trend indicates that increasing $Ti_3C_2T_x$ MXene content (1–10 vol.%) in the B_4C matrix enhances hardness due to the formation of TiB_2 phases, which improves densification and reinforces the B_4C matrix. Compared to traditional bulk TiC, 2D MXene sheets provide a larger surface area and uniform coverage of B_4C particles, lowering diffusion energy and enhancing sintering rates. This study demonstrates a new approach to using MXene as a nanometer-thick additive to form uniformly distributed TiB_2 in B_4C to enhance its structural properties.

References

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Figures

Figure 1: Electrostatic gravity-assisted self-assembly (left) and material characterization (right) of spark plasma sintered MXene-B4C ceramic composites [1].