Abstract

Fe-B-C composites were produced, from boron carbide and iron powders, using spark plasma sintering. This provided information on the effects of rapid sintering on densification, composition and the microstructure of the materials produced. The composition range included a selection high Fe contents (69.3, 78 and 80.9 vol. % Fe-B_4C) and high B_4C concentrations (1, 3, 5 vol. % Fe-B_4C). The properties of the materials were investigated to determine the potential for using relatively cheap Fe and B_4C powders to produce hard, wear resistant materials.

High Fe-B_4C composites were sintered at 900, 1000 and 1100°C at 60 MPa. Densification increased with increasing temperature and at 1100° each composition achieved $\geq$ 97 % densification. The materials reacted during sintering with the main phases observed being Fe_2B and $Fe_3(B,C)$ whilst additional phases formed were FeB, C and $Fe_{23}(B,C)_6$.Comparing the phases that were produced to Fe-B-C phase diagrams showed deviations from expected compositions, indicating the non-equilibrium nature of producing the composites using SPS. Although the composites were not at equilibrium, all the B_4C reacted and could not be maintained, even with fast heating and cooling rates.

The properties of the materials were dependent on both densification and the phases that were present after sintering. Materials containing higher amounts of the Fe_2B phase showed higher hardness and fracture toughness results, up to 13.7 GPa and 3.5 MPa.m$^{0.5}$ respectively for the 69.3 vol. % Fe-B_4C. The materials were sensitive to grain and pore growth which negatively affected properties at 1100°C. The transverse rupture strength of 388.3 MPa for 80.9 vol. % Fe-B_4C composite was the greatest, and showed evidence of both intergranular and transgranular fracture. The strength was affected by a fine dispersion of porosity at the grain boundaries, throughout the material, and free carbon in the structure was detrimental to the strength of the 69.3 % Fe-B_4C. The wear rates were lower using Si_3N_4 wear balls compared to stainless steel balls, where 69.3 vol. % Fe-B_4C showed the best wear rates, 8.9×10^{-6} mm^3/Nm (stainless steel ball) and 1.77×10^{-6} mm^3/Nm (Si_3N_4 ball), due to the higher Fe_2B composition and free carbon acting as a lubricant during sliding.

1, 3 and 5 vol. % Fe-B_4C composites were sintered to densities above 97 % of theoretical at 2000°C and 30 MPa. The formation of a transient FeB liquid phase assisted densification. 1 % Fe-B_4C attained hardness and fracture toughness up to 33.1 GPa and 5.3 MPa.$m^{0.5}$ with a strength of 370.5 MPa. Thermal mismatch between the FeB phase and B_4C caused high residual stresses at the interface which led to cracking and pull-out of the FeB phase. Residual carbon at the grain boundary interface exacerbated the pull-out effect. Increasing Fe and the subsequent FeB phase had an embrittling effect. The materials suffered severe wear of up to 36.92×10^{-6} mm^3/Nm as a result of the pull-out with the remaining porosity acting as a stress raiser.

20 vol. % of the Fe in each system was substituted with Ti to reduce the presence of residual carbon. Although in some case the properties of the respective compositions improved, residual carbon was still present in the composites.