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Microstructural Analysis of Novel Ceramic Composites Manufactured by Reactive Metal Penetration (RMP)

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Reactive metal penetration (RMP) processing involves submerging a sacrificial ceramic preform into a molten metal bath for a given time length. Following the immersion chemical reactions take place within preform between the ceramic and the molten metal. The goal is to produce materials with increased strength, hardness, and wear resistance. So far, the research on RMP produced materials focused on the Al_2O_3-Al alloy system, due to the convenience of melting aluminum and aluminum alloy in atmospheric conditions [1]. A fairly recent scientific report provides the theoretical criteria for the formation of ceramic-metal composite by immersing sacrificial oxide preforms in molten metal's, other than aluminum alloys [2]. The criteria are: (1) The produced oxide must have a smaller volume than the sacrificial one; (2) The produced oxide must be more stable than the sacrificial oxide (the free energy of formation of the produced oxide mast have a more negative value than that of the sacrificial one); and (3) the processing temperature must be higher than the melting point of the reductive metal but lower than its boiling point. Based on these criteria it seems possible to produce Ni-TiO composite by RMP starting with NiO sacrificial oxide as perform and molten Ti as reductive agent. Moreover, the by-product Ni might combine with Ti, eventually forming a NiTi phase.

In the present work two different metal-ceramic composite materials were synthesized using NiO and SiO_2 preforms reacted with molten Ti and molten Al-Fe, respectively. Microstructural, chemical and crystallographic investigations of obtained material were performed using light and electron microscopy (SEM and TEM), XEDS and XRD. Figure 1(a) shows a bright field light micrograph of a cross-sectioned composite material synthesized by RMP of Ti and NiO. The micrograph revels that two or more phases are present in the sample. The brighter phase seems to be a metal while reminder seems to be a porous phase. The existence of a porous phase was confirmed by SEM imaging, Figure 1(b). BSE imaging combined with XEDS analysis indicates the existence of one metallic phase and three ceramic phases, as shown in the Figure 2. XRD investigations confirmed that Ni, TiO and Ni_3TiO_5 phases were formed after transformation. It must be noted that although the metal-ceramic composite material had been obtained, the NiO sacrificial oxide was not completely transformed. Also, no NiTi phase was observed in the composite. One explanation might be related to the fact that the volume of molten Ti was smaller than the volume of the NiO preform, due to the melting conditions. The increase of molten Ti volume resulted in the preform destruction due to the violent thermite reaction with NiO. In an attempt to slow down the thermite reaction TiO_2 powder was mixed with NiO. However, for various ratio of TiO_2-NiO powder mixtures the rapid thermite reaction still occurred in every single experiment performed so far. In order to control the thermite reaction alternative fabrication routes are currently explored. For the two composite materials synthesized in this project the crystallographic orientation relationships among various phases are currently under investigation using TEM electron diffraction techniques.

References:

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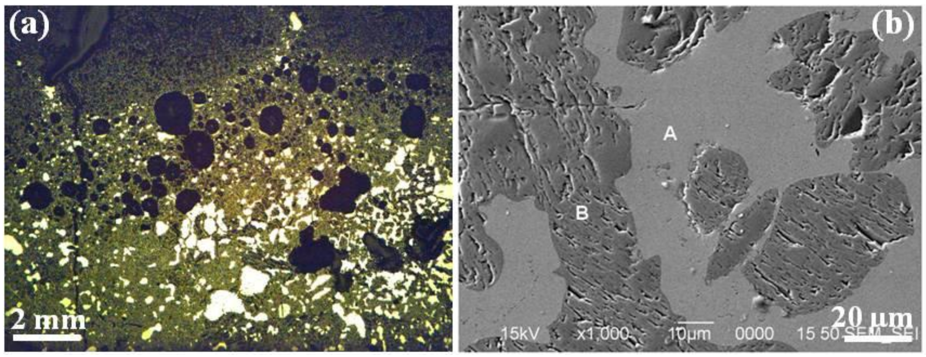

Figure 1: (a) Bright field LM image of a cross-sectioned sample of Ni-TiO composite obtained by RMP. (b) Secondary electron image of the transformed sample: (A) compact metal phase; (B) porous ceramic phase.

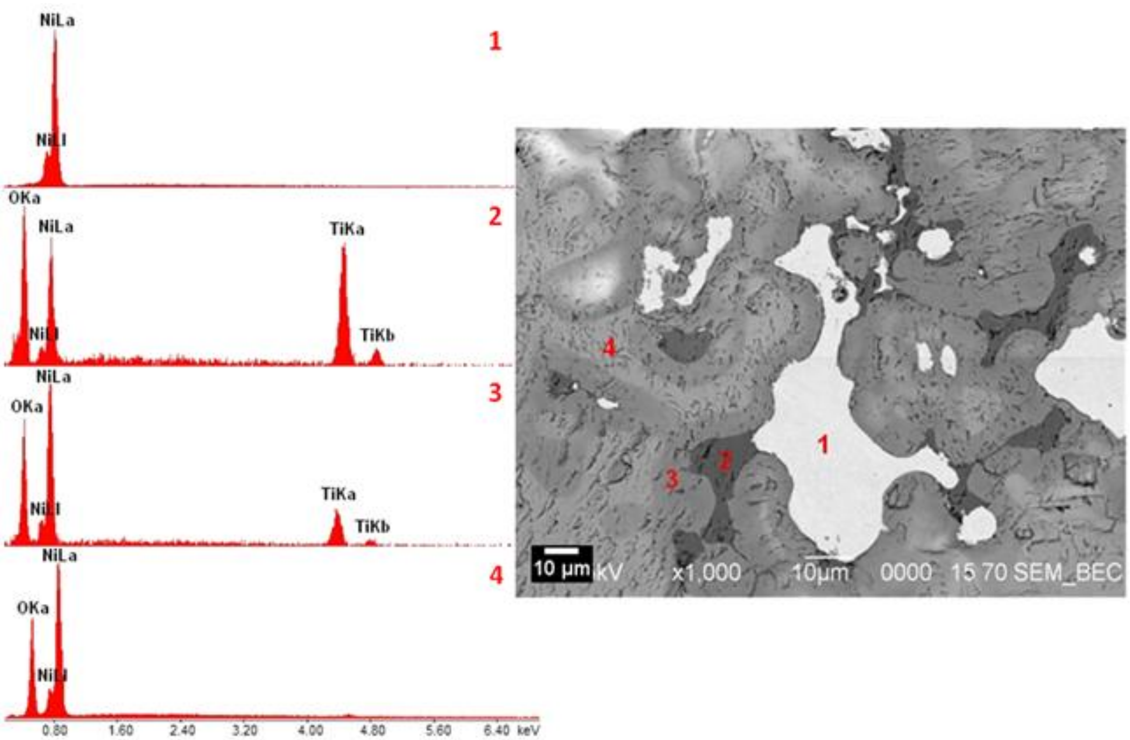

Figure 2: Backscattered electron image of cross-sectioned Ni-TiO composite showing four different shades, and corresponding XEDS spectra.

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