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Nanostructured Composites Using High-Energy Milling and Instrumented-HIP

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Abstract - High energy milling is used to fabricate nanostructured metal matrix composite powders. A high temperature eddy current sensor (HiTECS) is used to monitor in real-time the densification of a compact during Hot Isostatic Pressing (HIP). The combination of these technologies enabled us to consolidate nanostructured refractory metals and alloys powders and nanostructured aluminm reinforced with multi-walled carbon nanotubes into fully dense composites with the desired micostructure. HiTECS is used to identify the lowest temperature required to achieve full densification. As a result, the exposure to high temperature is minimized and the microstructure of the composite is controlled.

High energy milling is used to fabricate nanostructured metal matrix composite powders. A high temperature eddy current sensor (HiTECS) is used to monitor in real-time the densification of a compact during Hot Isostatic Pressing (HIP). The combination of these technologies enables us to consolidate (1) nanostructured refractory metals and alloys powders and (2) nanostructured aluminm reinforced with multi-walled carbon nanotubes into fully dense materials while maintaining the desired microstructure. The measurements made with HiTECS are used to track the densification rate and identify the lowest temperature required to achieve full densification. As a result, the exposure of the nanostructured material to high temperature is minimized and the microstructure of the final product is controlled. HiTECS is qualified up to a maximum temperature of 1250^{o}C and unlimited pressure. On-going development will increase the temperature capability up to 1550°C.

Several blends of tungsten and binder powders have been mechanically alloyed by high-energy milling resulting in nanostructured particulate material. These materials were subsequently consolidated to full density using instrumented-HIP. The change in canister diameter, shown in Figure 1, approaches zero as the temperature approaches 1025^{o}C, an indication that full density has been reached. The nanostructured powder had a lamellae size of 30 and 60 nm, and subsequent exposure to high temperature during HIP does not result in excessive grain growth. The Vickers hardness of the fully dense nanostructured composites was up to 1200.

Mixtures of pure aluminum with variety of additives such as Boron Carbide, Silicon Carbide and Multiwall Carbon Nanotubes (MWCNT) were used to produce Al-based nanocomposite powders in a high-energy mill. The composite powders were consolidated using instrumented-HIP to produce nanostructured metal matrix composites. Imaging of the fully dense composite of aluminum-MWCNT showed that the composite retained the nanostructure imparted during high-energy milling. This can be seen at 550X in Figure 2, where the lamellar structure is very apparent. The compressive strength of the composite reached 386 MPa. The amount of additive has a big influence on the consolidation parameters. This paper will discuss the effects of composition on the consolidation behavior, microstructure, and properties of these nanostructured composites.

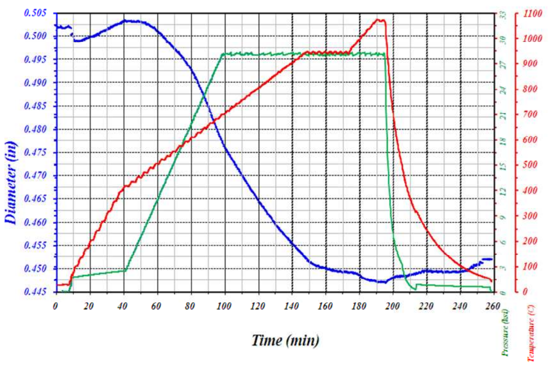

Figure 1. Data measurement during consolidation using an instrumented-HIP. Full density is achieved once the diameter curve is flat.

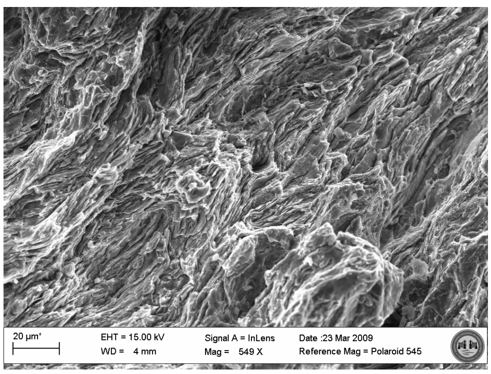

Figure 2. An Al-based nanostructured composite was produced by high-energy milling followed by instrumented-HIP. The fully dense composite retained a lamellar microstructure.