NIRT/GOALI: Fundamental Study of Bulk Magnesium Alloy Matrix Nanocomposites Fabricated by Ultrasonic Cavitation Based Solidification Processing

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Project Overview:

This NIRT research program is to advance both the fundamental understanding and knowledge of ultrasonic cavitation based solidification processing of complex bulk Mg MMNC materials/components and their processing/structure/property relationships. Cast bulk Mg alloy matrix nanocomposites can have a widespread impact on the automobile and aerospace industries by significantly improving the vehicle energy efficiency and performance. One of the major tasks of this NIRT program is to characterize the micro/nano structure of the resultant nanocomposites. The dislocation structure in the matrix around nanoparticles will be examined to understand the mechanism of strengthening by nanoparticles.

Motivation:

Magnesium alloys--one third lighter than an equal volume of aluminum alloys--are one of the lightest metallic structural materials and are very attractive for applications in automotive and aerospace systems. The need for complex structural components of high performance magnesium materials is expected to continuously increase as automotive and aerospace industries are forced to improve the energy efficiency of their products.

Nanoparticle reinforcements can markedly increase the matrix mechanical strength by more effectively promoting particle hardening mechanisms than micron size particles. A fine and uniform dispersion of nanoparticles provides a good balance between the strengthener (non-deforming particles) and inter-particle spacing effects to maximize the yield strength and creep resistance (by mechanisms such as dislocation bowing around the particles and pinning down dislocations at the particles by rapid diffusional stress relaxation at elevated temperatures) while retaining the good matrix ductility [1-3]. It is expected that the properties of metals reinforced by ceramic nanoparticles (less than 100 nm), that is, metal matrix nano-composites (MMNCs), would be enhanced considerably (e.g. superior strength and creep property at elevated temperatures, higher fatigue life, and better machinability) while the ductility is retained.

With the demand of mass production, the cost of nanoparticles (and other nano building blocks) will be significantly lower, which will make the production of MMNCs cost effective. Moreover, even a small percentage of nanoparticles (less than 5%) can considerably enhance properties, and when used in combination with low-cost processing, will be more economical (even with the present cost of nanoparticles) than creep-resistant magnesium alloys produced by adding rare earth elements.

Structural components, such as engine blocks, are often both large in volume and complex in shape, and current processing technologies are neither reliable nor cost effective for mass production of complex Mg MMNC structural components in spite of their superior properties. It is desirable to cast Mg MMNC components with good reinforcement distribution and structural integrity. However, it is extremely challenging for the conventional mechanical stirring method to distribute and disperse nano-scale particles uniformly in metal melts due to their large surface-to-volume ratio and their poor wettability in most metal melts, which easily induce agglomeration and clustering. Thus, there is a strong need for a cost effective and reliable process that enables efficient dispersion of nanoparticles in metal melts for solidification processing of high performance bulk MMNCs.

Physics of Ultrasonic Cavitation Based Processing:

High-intensity ultrasonic waves (acoustic waves with an intensity above 10^6W/m^2 and a frequency, f, above 18 kHz) are especially useful for liquid-based materials processing in that they generate important non-linear effects in liquids, such as transient cavitation and acoustic streaming [4,5]. Most importantly, acoustic cavitation involves the formation, growth, pulsating and collapsing of tiny bubbles (in the order of microns) in liquid under cyclic high intensity ultrasonic waves. Thousands of micro bubbles will be formed, expanding during the negative pressure cycle and collapsing during the positive pressure cycle. By the end of each cavitation cycle, the micro bubbles implosively collapse, producing transient (in the order of 10^{-9}s) micro "hot spots" that can reach temperatures of above 5000ºC, pressures in the order of 100~1000MPa (depending on ultrasonic intensity and liquid material), and heating and cooling rates above 10^{10} K/S. The shock wave following the bubble collapse generates a tremendous micro scale impact that has a speed in the order of the speed of sound. It is envisioned that strong micro scale transient cavitations can effectively distribute and disperse nanoparticles into alloy melts and also enhance their chemical reactivity and wettability, thus making the solidification processing of high performance lightweight Mg nanocomposites feasible.

Results:

Fig.1 shows the morphology and distribution of SiC nanoparticles in the magnesium matrix. It can be seen that nanoparticles are well distributed and dispersed, although there are some SiC agglomerates ~100-300nm in the matrix. Tensile tests were done on the Mg/2%SiC composite samples. The curves of stress vs. strain for pure Mg and Mg/2% SiC composites were shown in Fig.2. It can be seen that the mechanical properties of Mg were improved significantly by adding 2% SiC nanoparticles.

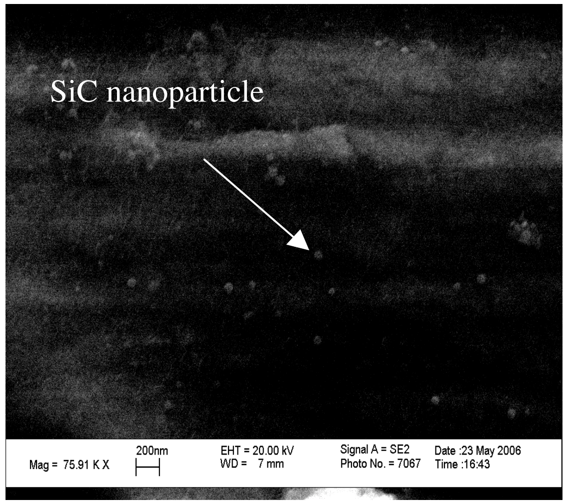

Fig.1. Morphology of Mg/2% SiC nano composites

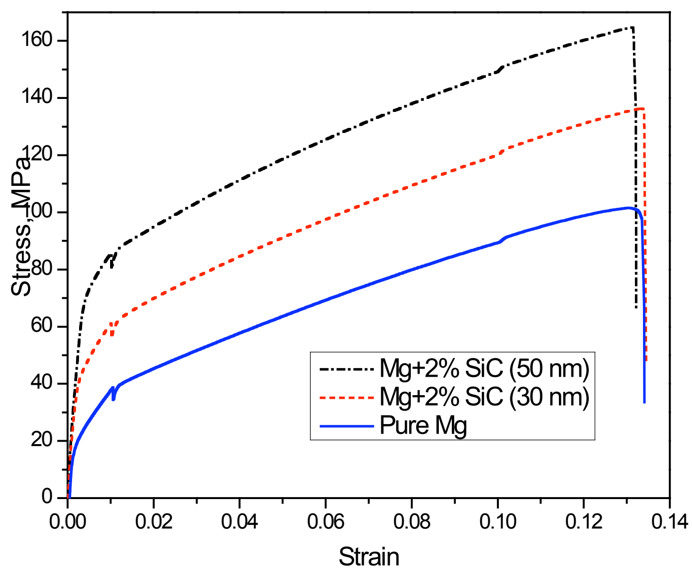

Fig.2. Tensile results on Mg and Mg/2% SiC composite

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