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# Ultrasonic-assisted fabrication of metal matrix nanocomposites

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When fine ceramic or other hard particles are imbedded into "soft" metal matrix to form metal matrix composites (MMCs), the properties of the matrix materials can be substantially improved/strengthened [1–5]. The strengthening mechanism for MMCs has been studied by many researchers [e.g., 2, 5]. It is hypothesized that the properties of metal matrix composites with imbedded nano-sized ceramic particles (1.0–100 nm), termed MMNCs, would be enhanced considerably even with a very low volume fraction.

Currently, mechanical mixing (e.g., high energy ball milling) of metallic and ceramic powders is generally used for the study of the characteristics of MMNCs [6]. To mix nano-sized ceramic particles, it is energy- and time-consuming as well as costly. Casting, as a liquid phase process, is well known for its capability to produce products with complex shapes. It will be desirable to produce as-cast lightweight components of MMNCs with good reinforcement distribution and structural integrity. However, nano-sized ceramic particles present difficult problems: it is extremely difficult to disperse them uniformly in liquid metals because of their poor wettability in metal matrix and their large surface-to-volume ratio, which easily induces agglomeration and clustering.

High-intensity ultrasonic waves may be useful in this context in that they generate some important nonlinear effects in liquids, namely transient cavitation and acoustic streaming [7–10]. Acoustic cavitation involves the formation, growth, pulsating and collapsing of tiny bubbles, producing transient (in the order of microseconds) micro "hot spots" that can reach temperatures of about 5000 °C, pressures of about 1000 atm, and heating and cooling rates above $10^{10}$ K/s [11]. The strong impact coupling with local high temperatures can also enhance the wettability between liquid metals and particles, thus making the preparation of as-cast composites with microparticles successful [12–14].

It is envisioned that strong microscale transient cavitations, along with macroscopic streaming, might effectively disperse nanoparticles into alloy melts and also enhance their wettability, thus making the production of as-cast high performance lightweight MMNCs feasible. This study is to investigate the feasibility of this concept.

As shown in Fig. 1, the experiment setup consists of processing parts and control parts. The melt metal (aluminum alloy 356) was held in a ceramic crucible and a titanium waveguide that was linked to a 20 kHz, 600 W ultrasonic transducer (Misonix) was dipped in the melt. During the fabrication of MMNCs, the aluminum melt pool was covered by argon gas. One temperature probe was used to monitor the melt temperature. The nanoparticle used in this study was $\beta$-SiC (average size $\leq$30 nm). The processing temperature was about 100 °C above the alloy melting point (610 °C).

Fig. 2a shows the microstructures of "pure" aluminum alloy samples without ultrasonic processing. Dendritic grains are clearly revealed. Fig. 2b shows the microstructures of the cast aluminum alloy samples with 2.0 vol% SiC nanoparticles under ultrasonic processing. The grain sizes from the samples under ultrasonic processing are much smaller. It seems that particle dispersion is quite homogeneous since no nanoparticle clusters could be found under the optical microscope. Further study with SEM has been conducted.

Fig. 3 shows an SEM image of the nanocomposite with approximately 2.0 vol% nanoparticle fabricated by ultrasonic-assisted casting. The ultrasonic vibration was continuously applied to the solidifying alloy for approximately 1.5 h until the sample had cooled down to room temperature. The SEM image demonstrates that the nanoparticles are dispersed well, although some small clusters (100 nm) remain in the microstructure. It is believed that high intensity ultrasonic generated strong cavitation and acoustic streaming effects. Transient cavitations could produce an implosive impact strong enough to break up the clustered particles to disperse them more uniformly in liquids. Moreover, acoustic streaming, a liquid melt flow due to acoustic pressure gradient, is very effective for stirring [10, 15]. Thus, a better understanding of these nonlinear effects in melts with nanoparticles will be essential to optimize the process parameters to further disintegrate the small clusters shown in the SEM picture.

Fig. 4 shows the hardness measurements on samples under different conditions or compositions. With a 2.0 vol% SiC nanoparticles, an approximately 20% hardness improvement was achieved. However, the hardness of "pure" alloy samples under ultrasonic processing is lower than that of "pure" alloy samples without ultrasonic processing in these initial experiments. After a more careful microstructure inspection, more microcavities were found in the aluminum alloy samples that were processed with ultrasonic processing than those without ultrasonic processing. These microcavities can degrade the hardness and other mechanical properties of as-cast samples. It is well known that ultrasonic waves can be used for degassing to lessen the cavities during casting [10]. However, if the acoustic streaming is too violent on the melt surface that is exposed to air, as occurred in our preliminary experiments, the violent flow stirred by the streaming could trap argon bubbles into the melts, forming more microcavities in the cast samples after solidification. These microcavities can be eliminated by use of optimized process parameters in a vacuum environment.

This paper presents experimental results on ultrasonic-assisted casting of aluminum alloy based matrix nanocomposites. It validates the feasibility of this new fabrication method for metal matrix nanocomposties (MMNCs). Nonlinear effects of high intensity ultrasonic waves are effective in refining grain sizes and dispersing nanoparticles in metal matrix. A total of 20% hardness improvement has been achieved with a 2.0 vol% nanoparticle addition in aluminum alloy. Further study to optimize the process parameters is needed to further improve the properties of MMNCs.

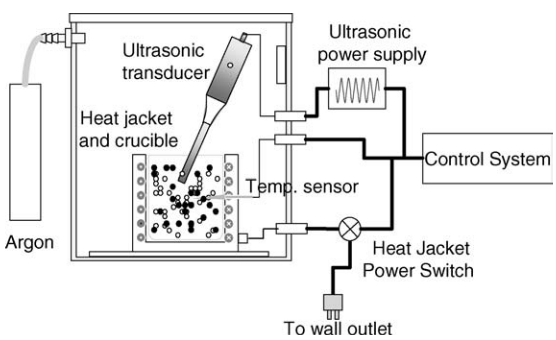
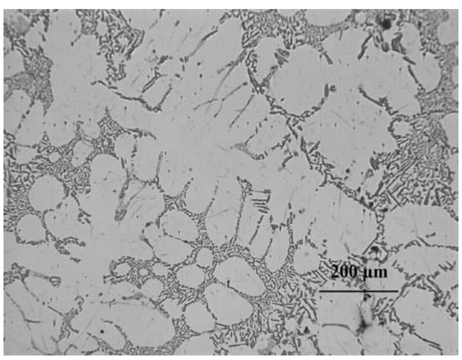
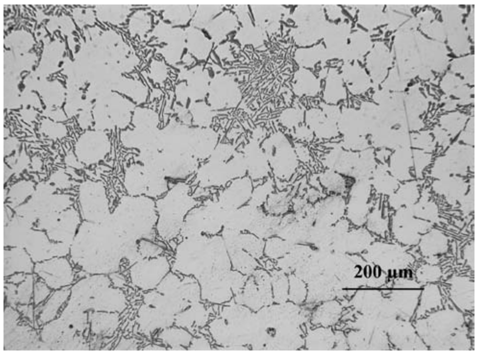



*Figure 1* Experiment setup.




(a)




(b)

*Figure 2* (a) Microstructure of Al-alloy by regular casting. (b) Microstructure of MMNC fabricated with ultrasonic waves.

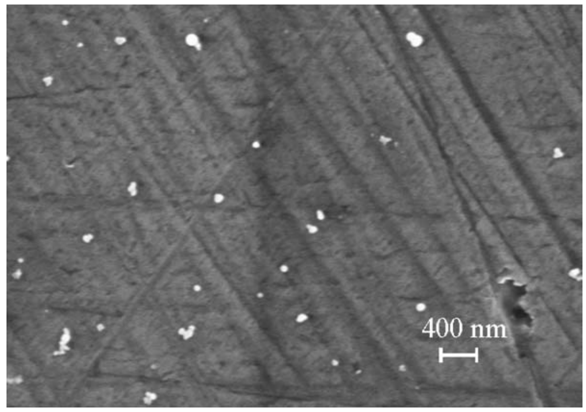



*Figure 3* SEM picture of nanocomposite.

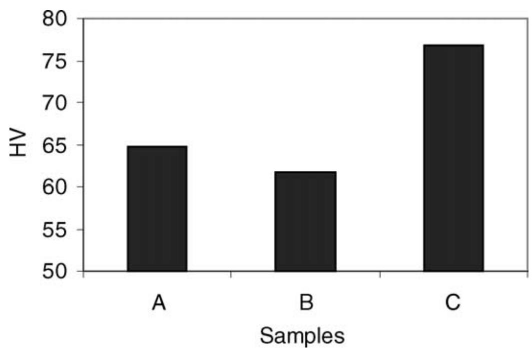



*Figure 4* Hardness measurements: (A) Aluminum alloy by regular casting, (B) Aluminum alloy by ultrasonic-assisted casting, and (C) Aluminum alloy matrix nanocomposite by ultrasonic-assisted casting.

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