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THE EFFECT OF HOMOGENOUS DISTRIBUTION OF NANO-PARTICLES THROUGH ULTRASONIC CAVITATION METHOD – A REVIEW

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ABSTRACT

In recent years, Metal Matrix Nano Composites (MMNC) research is going on, in a greater extent. MMNCs overcome many limitations compared with conventional metal matrix composites (micro inclusions) such as poor ductility, low fracture toughness and machinability. Casting as a liquid phase process, is well known for its capability to produce as cast light weight components of MMNC 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. Transient cavitations could produce an implosive impact strong enough to break up the clustered fine particles and disperse them more uniformly in liquids. It is envisioned the strong micro scale transient cavitations, along with macroscopic streaming, might effectively disperse & distribute nanoparticles into melts and also enhance wettability, thus making the production of as-cast high performance light weight MMNC feasible in ultrasonic cavitation method.

***Key words**: ultrasonic cavitation method, Aluminium metal matrix, nano-composites*

1. Introduction

Metal Matrix NanoComposites (MMNC) are the materials in which reinforcements of nanoscale are embedded in a ductile metal or alloy matrix. Dispersion of nanoscale materials in metal matrix is a challenging task due to their poor wettability in metal matrix and their large surface to volume ratio, which easily induces agglomeration and clustering.

The phases of compression and rare fraction are responsible for the ultrasonic cavitation. This problem may be solved by ultrasonic waves as a means for dispersing reinforcements throughout the matrix.

Ultrasonic waves are the waves of frequency above 17~20 kHz and generated by mechanical vibrations of frequencies higher than 18 kHz. When these waves propagate into liquid media, alternating compression and expansion cycles are produced. During the expansion (rare fraction) cycle, high intensity ultrasonic waves make small bubbles grow in the liquid. When they attain a high volume at which they can no longer absorb enough energy, they implode violently. This phenomenon is known as cavitation. During implosion, very high temperatures and pressures are reached inside these bubbles.

Ultrasonic wave generation from its source. In order to achieve a uniform dispersion and distribution of nanoparticles in aluminum matrix nanocomposites, developed an innovative technique that combined solidification processes with ultrasonic cavitation can produce transient (in the order of nanaoseconds) micro “hot spots” that can have temperatures of about 5000ºC, pressures above 1000 atm and heating and cooling rates above 10^{10} K/s.

2. Principles of Ultrasonic Cavitation

High intensity ultrasonic waves generate non-linear effects in liquids, namely transient cavitation and acoustic streaming ,which are mostly responsible for refining microstructures, degassing of liquid metals for reduced porosity, and dispersive effects for homogenizing. Transient cavitation is a microscopic effect and acoustic streaming is a macroscopic effect.

Transient cavitation involves the formation, growth, pulsating, and collapsing of micro-bubbles in liquids 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).

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3. Cavitation

Cavitation is the formation of vapor or gas bubbles in a liquid caused by reduction in pressure at constant temperature. This is in contrast to the nucleation of bubbles due to an increase in temperature above the saturated vapour/ liquid temperature, which is called boiling. The dynamic pressure reduction can be achieved in many ways, of which ultrasonic waves one is Hence it is termed as ultrasonic cavitation.

After cavitation, bubbles are formed by a dynamic pressure reduction, which are subjected to a pressure increase. As the growth of the bubbles stops, the bubbles begin to collapse. If only vapor is present in the bubbles, the collapse becomes more severe.

They are very few beneficial applications of cavitations, such as high speed cavitation water jets for rock-cutting and dental applications. With the evolution of MMNC,ultrasonic is also finding their place in fabrication of the same.

4. Processing Techniques

The Aluminium matrix nano-composites-Al MMNC can be classified in to three main groups. Solid state processes include high energy ball mill and powder metallurgy (PM) techniques with modifications in the processing step such as hot isostatic pressing (HIP), cold pressing followed by sintering treatment and extrusion [14].

Liquid state casting process include stir casting,ultrasonic- assisted casting and semi solid processing includes a combination of rheocasting and squeeze casting and semi-solid route stir casting [14].

5. Results And Discussion

The uniformly distributed SiC nanoparticles in the Al melt at 30 µm amplitude was the prime reason for the enhancement in the tensile strength and hardness Fig.1a. of the MMNC [3]. The effects of ultrasonic amplitude on processing the AA6061/1.25 vol. % SiCp MMNC were successfully carried out in this research work.

The results showed that the MMNC samples processed with 30 µm of ultrasonic amplitude yields better dispersion of SiC nanoparticles in the AA6061 melt compared to that of the MMNC processed with 15 µm in Fig.1b and 50 µm in Fig.1c of ultrasonic amplitudes.

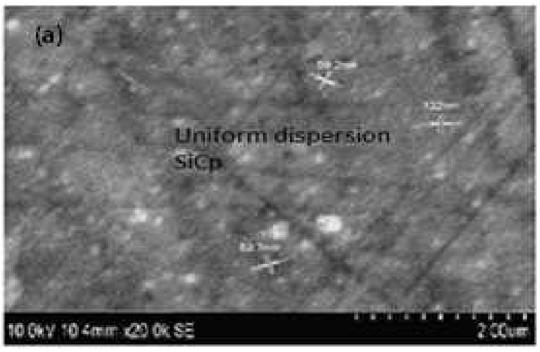

Fig.1a SEM Micrographs showing SiC$_p$ dispersion in AA6061/1.25 vol. % SiC$_p$ (30 µm) Ref [3]

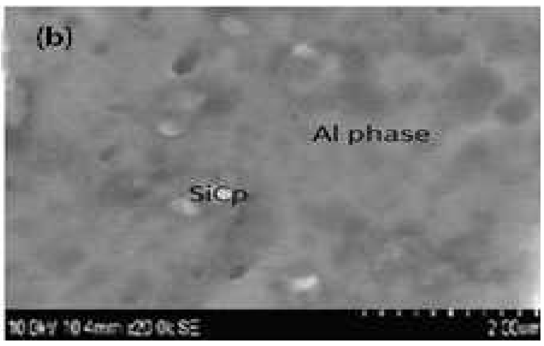

Fig.1b SEM Micrographs showing SiC$_p$ dispersion in AA6061/1.25 vol. % SiC$_p$ (15 µm) Ref [3]

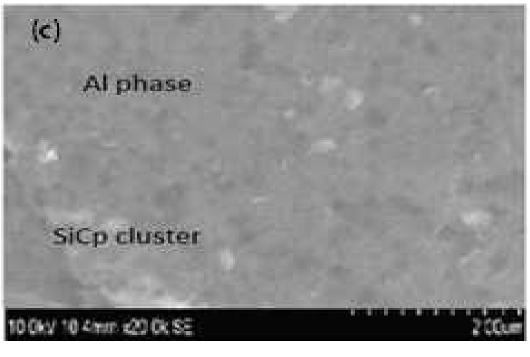

Fig.1c SEM Micrographs showing SiC$_p$ dispersion in AA6061/1.25 vol. % SiC$_p$ (50 µm) Ref [3]

The reason should be attributed to at 30 µm of ultrasonic amplitude; the generated intensity is approximately equal to 20 times the threshold intensity required for the development of full cavitation. The ultrasonic cavitation technique proved as a novel route for manufacturing metal matrix composite materials. In this present work, the purpose of ultrasonic cavitation in the metal matrix composite was studied. Different weight percentage of Al 6061-SiCp composite materials were fabricated by ultrasonic cavitation method and the fabricated materials were subjected to hot rolling process to reduce the casting defects [4].

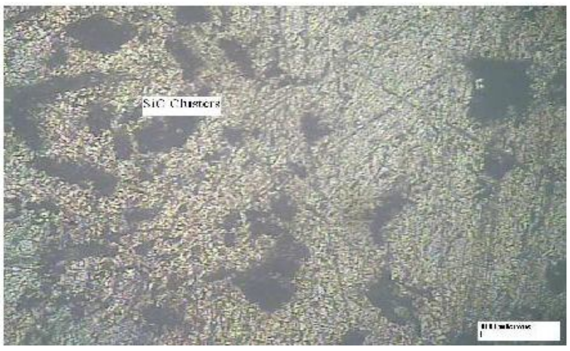

Fig.4 Al 6061-Sip composite with 15%SiC. Ref [4]

It was observed that the particle tends to agglomerate more with increase in the weight percentage of SiCp. Agglomeration of particles Fig.4 makes the material as weaker structure hence the reduction in tensile strength. [4]. The microstructures of "pure" aluminum alloy samples without ultrasonic processing. Dendrite grains are clearly revealed. Fig 4 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 nanoparticles clusters could be found under the optical microscope [6].

Composite specimens were subjected to tension and hardness test. From the experimental results it was observed that the tensile strength values were significantly improved in 5 wt% and 10 wt% of SiCp. Further addition of SiCp in the mixture reduces the tensile strength. Also, the hardness of the material increases and ductility decreases as the particle percentage increases [4].

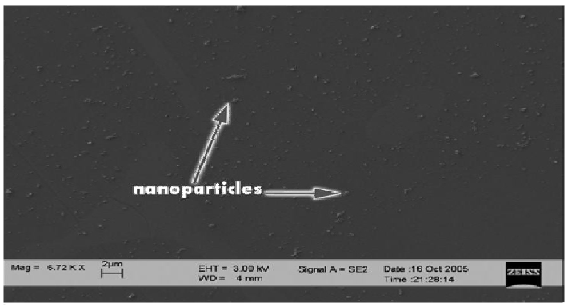

Fig.5 Al 6061 fully dispersion 10% Wt SiC Ref. [4]

5.1 Fabrication of Composites

Optical microscopy and scanning electron microscopy images show the evidence of homogeneous distribution Fig.5 of SiCp in matrix element. The tensile strength and hardness of Al 7075 alloy reinforced with 0.5 wt% of SiC and B_4C nanoparticles were examined and compared with 0 wt% of Al alloy. From the SEM micrograph the nanoparticles are well dispersed in Al matrix and offers improved results than 0 wt% Al alloy. Out of B_4C and Sic nanocomposites, the dispersion of nano B_4C particles is better than SiC nanoparticles because of their wettability property. This offers improved results for B_4C while comparing to SiC nanoparticles. It can be concluded that the use of nanoparticles gives better results in ultimate tensile strength and hardness. [5] The feasibility of ultrasonic cavitation based dispersion of nanoparticles in A356 was theoretically studied and validated by analytical modeling, particularly for a simplified two- nanoparticles system in A356 melt. An experimental system for ultrasonic cavitation based solidification processing was fully developed and alloy A356 nanocomposites were fabricated and characterized.

With optimized processing parameters, the tensile test results showed that, with only 1.0 wt% nano-sized SiC, the ultimate tensile strength (UTS) and yield strength of the nanocomposites were improved approximately 100% while ductility is retained. Micro/nano structure study shows that good nanoparticle distribution and dispersion in the Al matrix were achieved. EDS in TEM showed that the processing was well protected from oxidation and a single nanoparticle was clearly identified by Fig.5

The nanocomposites with approximately 2.0 vol% nanoparticles fabricated under 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 [6].

With a 2.0 vol% SiC nanoparticles approximately 20% hardness improvement was achieved. [6].The hardness of “pure” alloy samples without ultrasonic processing in these initial experiments. After a more careful microscopic 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 [6].

Experimental results on ultrasonic-assisted casting of aluminum alloy based matrix nanocomposites. It validates the feasibility of this new fabrication method for metal matrix nanocomposites (MMNC). Nonlinear effects of high intensity ultrasonic waves are effective refining grain sizes and dispersing nanoparticles in metal matrix. A total of 20% hardness improvement has been achieved with a 2.0 vol% nanoparticles addition in aluminum alloy [6].

The nano-sized SiC particles are dispersed well in the matrix and yield strength of A356 alloy was improved more than 50% with only 2.0 wt% of nano-sized SC particles. Partial oxidation of SiC nanoparticles resulted in the formation of SiO_2 in the matrix. The study suggests that strong ultrasonic nonlinear effects could efficiently disperse nanoparticles (less than 100 nm) into alloy melts while possibly enhance their wettability, thus making the production of as-cast high performance lightweight MMNC feasible [7].

The 1kW power ultrasonic transducer with 30 minutes sonication time for 0.5 wt% of reinforcement is sufficient to disperse nanomaterials in 500 grams of aluminum melt in Fig.6 It can be concluded that the use of nanomaterials shown an improvement in tensile properties and hardness with decrease in ductility. Though there is decrease in ductility for all the cases, it is within permissible range i.e. 4-6% of A356 alloy. Due to their unique properties, carbon nanotubes content affects significantly mechanical properties of composites. Meanwhile, the 0.5 wt% nanotube composites found to exhibit the highest yield and tensile strength and good retention of ductility. The maximal increments of yield and tensile strength of the composite, compared with the A356 matrix are 71.6% and 70.27% respectively. The ductility of SiC reinforced nanocomposites would be reduced due to the micro-clusters. However, the tensile testing showed that the ductility of nanocomposites was still high. This possibly can be explained from the following two aspects: Firstly, although micro-clusters are appeared, most of the nanoparticles in the micro-clusters are still separated by aluminum in Fig.6 Secondly, the negative effects of some micro-clusters were balanced by the positive effects of the grain refining effects and strengthening effects of the well-dispersed nanoparticles [12].

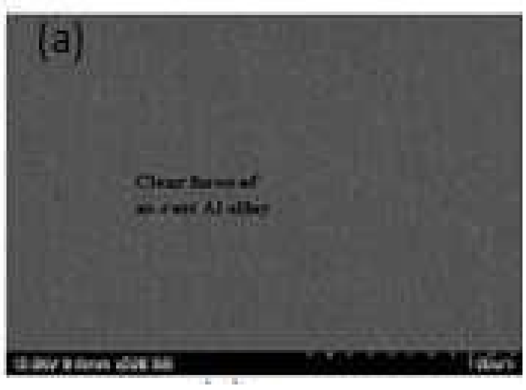

Fig.6 A 356 matrix alloy Ref [10]

Bulk Al-based nanocomposites with nanosized SiC were fabricated by an ultrasonic based manufacturing process. The microstructure study shows that high- power ultrasonic is effective to disperse nanosized SiC particles in aluminum alloy A356 and enhances the wettability between particles and Al matrix. However, it is typical that a small amount of micro clusters remained in the matrix. The EDS spectrum shows that the process is well protected from oxidation. The superior nanoparticles dispersion resulted in significantly improved mechanical properties. [8]

Hardness and tensile strength of A356 reinforced with different weight percentage (0.1-0.5 wt %) of SiC nanoparticles was examined and compared with pure alloy and 0.5 wt% micro SiC particle reinforced alloy. With the increase in reinforcement ratio, tensile strength, hardness of nano SiC reinforced composites were increased with no significant change in ductility. Whereas for micro composite, slight increase in strength, hardness and decrease in ductility were observed. The use of nanoparticles by top down approach also is permissible to use in the fabrication of metal matrix nanocomposites. However, it is advised to use nanoparticles produced by bottom up approach for the fabrication of nanocomposites in the view of ductility retention with the uniform increase of tensile properties [9].

Ultrasonic stirring prevents SiC agglomeration and reduce porosity levels in Fig.7 and combined effect of ultrasonic stirring and carbon inoculation improve hardness. Al_4C_3 carbide could not be detected but Al_4SiC_4 particles are identified by EDS and XRD analysis [11].

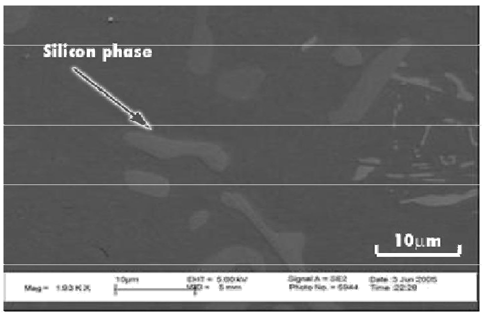

Fig.7 Nano composites Ref [10]

By use of HRTEM, the nanostructure study indicates that a good bonding Fig.8 was obtained and the lattice of the Al matrix gradually evolved to that of the nanoparticles [10].

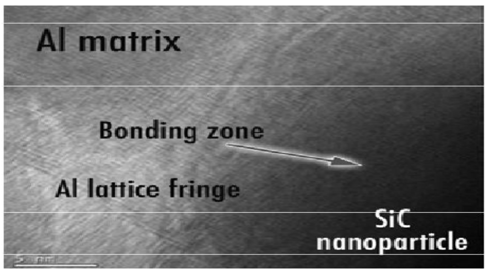

Fig.8 HRTEM image of bonding zone around Single particle in Al matrix at 850k Magnification Ref [10].

The particles of carbon black are amorphous in nature. In molten metal processing, the reinforcing particles are mixed directly into the liquid melt and exposure times are relatively long. As a result shows in the reinforcing particles may react with the liquid metal. The main reaction between aluminum and SiC is

$$4Al + 3SiC \text{----›} Al_4C_3 + 3\ Si$$

There is also the possibility of forming a ternary compound.

$$4Al + 4SiC \text{----›} Al_4SiC_4 + 3\ Si$$

Reaction between carbon black and liquid aluminum.

$$4Al_{(l)} + 3C_{(s)} \text{----›} Al_4C_{3(s)}$$

At 750ºC, the free energy of formation of Al_4C_3 is 168 KJ/mol. [11]

High intensity ultrasonic waves are capable of distributing and dispersing nanoparticles in the Mg matrix with non-linear effects in liquids, especially transient cavitation. From the high-resolution SEM observation, SiC nanoparticles are almost uniformly distributed in the matrix, although small clusters (less than 300 nm still exist in matrix. EDS analysis indicates that the SiC nanoparticles are partly oxidized. [13]

Compared to pure cast AZ91D cast AZ91D/5SiC yields Mg_2Si compounds. The Mg_2Si compound in the composites might be resulted from chemical reactions taking place during the ultrasonic processing of composites. Si could be introduced in the magnesium matrix by reactions between Mg and the SiO_2 layer that covers the surfaces of SiC nanoparticles. The XPS analysis also indicates the existence of SiO_2. [13].The micro hardness of nanoparticles reinforced magnesium composites improved with the increasing faction of SiC nanoparticles. The microhardness of AZ91D/5SiC increased by 75% compared to that of AZ91D. [13]

6. Conclusion

The ultrasonic cavitation technique proved as a novel route for manufacturing metal matrix composite materials. In this present review the purpose of ultrasonic cavitation in the metal matrix composite was studied. The dispersion of nano-particles was experimentally proved and characterized. A good bonding was obtained for the nano-particles as a reinforcement and the lattice of the Al matrix gradually evolved excellent base in the ultrasonic cavitation method is clearly proved, when compare with the ordinary conventional methods.

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