The International Journal Of Engineering And Science (IJES)
|| Volume || 3 || Issue || 12 || December - 2014 || Pages || 29-34||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Study on Processing and Mechanical Properties of nano SiC_p reinforced AA7075

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ABSTRACT

Light weight Metal matrix nano composites (MMNCs) have significance in aerospace, naval and other light weight applications. The ultrasonic cavitation based technique is found to be effective method to disperse nano particles uniformly and to produce a wide range of MMNCs. In this study, the uniform dispersion of nanoparticles in aluminum (AA7075) matrix resulted in enhanced mechanical properties. Various weight percentages of SiC nano particles are reinforced into the aluminum matrix. It is observed that there was a reasonably uniform dispersion of particles in the matrix. The hardness values, impact strengths and microstructures with various weight percentages are compared and presented.

***Key Words**: Metal matrix nano composites, Ultrasonic cavitaion, Silicon carbide nanoparticles.*

Date of Submission: 21 November 2014 Date of Accepted: 10 December 2014

I. INTRODUCTION

Metal matrix composites have been extensively studied in last two decades. Recently, Aluminum matrix composites reinforced by micro SiC_p particles were fabricated and their sliding wear behavior, temperature rise and coefficient of friction of composites were studied as a function of volume fraction[1].Mechanical properties such as tensile and fracture characteristics of aluminum AA2009 discontinuously reinforced with SiC_p are increased which is attributed to influence of residual stresses generated due to intrinsic differences in thermal expansion coefficients between the composite constituents[2].Also properties such as a Young's modulus and yield strength of as cast MMNCs have been improved by adding nano SiC particles in A356.Microstructural study with OM, SEM and EDS shows good dispersion of nano SiC particles in the matrix [3].The hardness of the aluminum alloy improved significantly by the addition of SiC particulates in Al2014 but density decreased with decreasing particle size where as porosity increased [4].

Now a days there has been increasing interest in the development of Carbon nanotubes (CNTs) reinforced composites. Carbon nanotubes reinforced aluminum matrix composites were fabricated by isostatic pressing followed by hot Extrusion techniques. Nano tubes are uniformly distributed in the composites and they act as bridges across the cracks, others are pulled out on fracture surfaces of composites and however CNTs react with aluminum2024 and form Al_4C_3 phases when temperature is above 656^oC. CNTs content affects significantly on mechanical properties of composites [5].Uniform distribution of CNTs is achieved by nano scale dispersion method in CNT/Al composites by introducing into an elastomer precursor [6]. Cha et al. found a molecular level mixing method in CNT/Cu composites by means of salt containing Cu ions [7]. Strong 8mol%Y_2O_3 stabilized zirconia (8YSZ)/silicon carbide nano composites were fabricated by hot pressing technique. The SiC content in nano composites increases the fineness and homogeneity in the microstructure. The total conductivity decreased with increasing SiC content due to the decrease in grain boundary conductivity, which should be related to the increase in grain boundary length and the decrease of effective volume of ionic conductor by SiC particles at grain boundary [8].Ultrasonic consolidation (UC) uses high frequency mechanical vibrations to produce a solid state metallurgical bond between metal foils. UC induces volume and surface effects in the material in which it is acting on. The high resolution back scatter diffraction is used to study the effects of the UC process on the evolution of microstructure in AA6061. UC leads to exceptional refinement of grains to a micron level along the bond area and affect the crystallographic orientation. Plastic flow occurs around the fibre which leads to the fibre embedding [9]. Aluminum matrix based composites, reinforced with SiC_p are age hardenable and can be strengthened through precipitation hardening process. For a given solutionizing temperature (S_t) of 530^oC it was observed that S_t as an individual has the maximum influence on fatigue strength of AA6061-SiC_p composite [10].Using shock wave consolidation, SiC particles are reinforced in to the titanium matrix composites. Using non destructive ultrasonic wave speed measurements the composites are tested for Young's modulus, bulk modulii and poison's ratio due the damage of particles[11]. The SiC particles with 5, 10, 20, 30 vol% in Al 6061 powder were extruded and heat treated at 843K.The longitudinal and transverse tensile tests were conducted. The distribution of residual stress was measured on the fracture surface. The plastic zone size decreased as the volume fraction of SiC particles increased. The particle diameter has an important influence on the fracture toughness. The particles equal to or larger than the critical size play an important role in the fracture initiation and fracture toughness [12]

II. EXPERIMENTAL PROCEDURE

The base material used in this study is AA7075 aluminum alloy has the following chemical composition-7.99Zn, 2.52Mg, 2.4Cu, 0.1Mn, Al balance.

SiC nano particulate of size 50 nm are selected in this study as its density is close to the Al, and thus they will not agglomerate in the matrix. The experimental setup consists of an electrical resistance heating unit for melting the AA7075 aluminum alloy, an EN-8 steel crucible, and melting point temperature 710^0C.

A Sonicator consists of ultrasonic transducer probe dipped into the melt for ultrasonic processing. The ultrasonic nonlinear effects disperse the nano particles uniformly into the aluminum matrix.

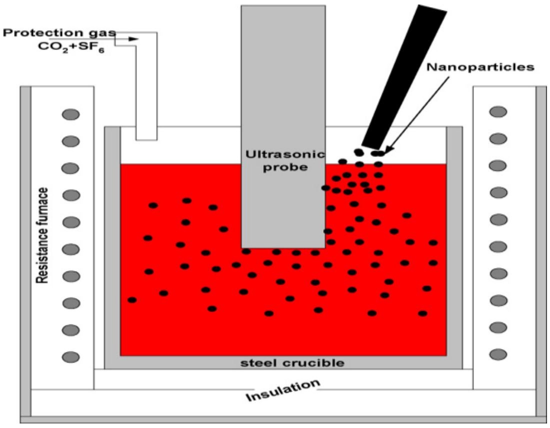

Fig.1. Sonicator with furnace

Various weight percentages of nano sized SiC particles (0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 1%, 1.5% and 2% by weight) are added to the melt during the cavitation process. The molten metal is protected from atmospheric air by Argon gas during melting. The molten metal was poured into a die of size 200x130x8mm^3 and plates were cast.

Fig.2. Casting of plates

The as cast plates are heat treated, (solutionzed at 560^0C for 1hr) and ageing is done at 160^0C for12hrs. The mechanical properties of the cast plates as well as heat treated plates are enhanced. For Microstructural analysis, MMNC cast plates are cut to size of 10x10x5mm^3, ground and polished to mirror finishing. The samples are etched with Keller's reagent (composed of 2ml HF, 3ml HCl, 5ml HNO_3 and 190ml water). Optical images and SEM images are taken to study the grain refinement, grain structures and elongations.

III. RESULTS AND DISCUSSION

The mechanical properties and microstructures are studied on the base metal and on the fabricated composites. The results are compared and presented below.

3.1. Hardness Tests

The SiC particles are added to the molten metal. During the addition, the particulate tend to float on the surface of the melt. The SiC nanoparticles have a slightly larger specific density than that of the molten aluminum alloy [13].The reasons for this are high surface tension of the melt and poor wetting between SiC particulate and the melt. Due to the application of high intensity ultrasonic waves, the acoustic streaming traps the nano particles in the melt effectively. Hardness of the composites is measured at different locations on the samples. The hardness increased nearly linear with various weight percentages of the nano SiC particulate. The hardness of the aluminum AA7075 alloy is found to be 108Hv.The hardness value of 1.5wt% of SiC MMNCs is-115Hv.The value is increased by10% compared with the base metal. The hardness values of the MMNC are plotted in the Fig-3.The plates are heat treated (solutionising and ageing) and hardness values are compared.

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Table.2.The hardness values of MMNCs

%by wt of nano SiC_p	Hardness of as cast metal-Hv	Hardness after **solutionisation-** Hv	Hardness after **ageing-** Hv
0.1	108	110	114
0.2	109	111	116
0.3	112	113	118
0.4	113	114	120
0.5	115	116	124
1.0	118	120	127
1.5	119	124	130
2.0	116	118	123

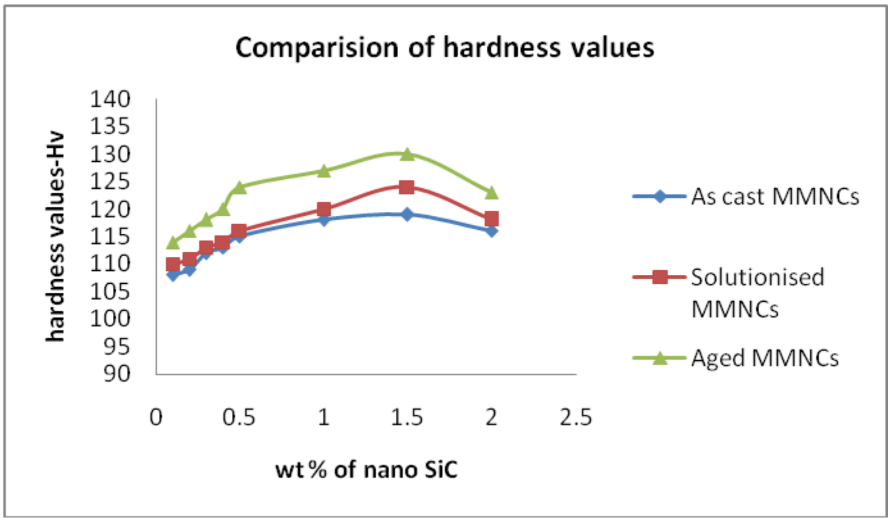

Fig.3. Hardness values of MMNCs for various wt% of nanoSiC_p

3.2. Impact Tests

Impact tests (Charpy type) are conducted on MMNCs, for various wt% percentages of nano SiC particulate (0.1, 0.2, 0.3, 0.4, 0.5, 1.0, 1.5, 2.0 wt %). The specimens are arranged as a simply supported beam with a span of 40mm and notch is kept on tension side (opposite to the striking edge). The impact energies absorbed are tabulated in Table-3. The impact strength of base metal is 8 joules.

Due to the addition of nano SiC particulate the grain sizes become less and grain boundary area increases, results in restriction to dislocation movements. Thus the grain refinement and elongation of grains occur, impact strength is more.

Table.3. Impact strengths of MMNCs

Wt% of nano SiC_p	0.1	0.2	0.3	0.4	0.5	1.0	1.5	2.0
Energy absorbed by MMNC(Joules)	8.5	9.5	10	12	13	13.5	14	12

3.2.1. The interaction between ultrasonic waves and nano-sized particles in aluminum melts.

Due to the application of high intensity ultrasonic waves the acoustic streaming traps the nano particles into the melt effectively. They generate some important non-linear effects in liquids, namely transient cavitation and acoustic streaming which are mostly responsible for benefits including refining microstructures, degassing of liquid metals for reduced porosity, and dispersive effects for homogenizing. Acoustic streaming, a liquid flow due to acoustic pressure gradient, is very effective for stirring. Acoustic cavitation involves the formation, growth, pulsating, and collapsing of tiny bubbles 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 one cavitation cycle, the tiny bubbles implosively collapse (in less than 10^{-6} s), producing transient (in the order of microseconds) micro "hot spots" that can reach temperatures of about 5000^0C, pressures of about 1000atms, and heating and cooling rates above 10^{10}K/s. The strong impact coupling with local high temperatures can potentially break nanoparticles clusters and clean the particle surface. Since nanoparticles clusters are loosely packed together, air could be trapped inside the voids in the clusters, which serves as nuclei for cavitations [15]. The size of the clusters range from nano- to micro-meters due to the attraction force among nanoparticles and the poor wettability between nanoparticles and molten metal. Although these SiC clusters appear as micro clusters, most of the nanoparticles in the micro-clusters are still separated to single nanoparticle or sintered nano-clusters. The negative effects of some SiC micro-clusters are balanced by the positive effects of the grain refining and strengthening effects of the well dispersed SiC nanoparticles.

Nanoparticles reinforcement can significantly increase the mechanical strength of the matrix 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, such as SiC nanoparticles) and inter-particle spacing that results in maximizing the hardness. A combination of good distribution and dispersion of micro particles can be achieved by mechanical stirring. However, to produce aluminum matrix nanocomposites, it is extremely challenging for the conventional mechanical stirring method to distribute and disperse nanoparticles uniformly in molten metal because of the much higher specific surface areas in nanoparticles.

Hardness of the composites is measured at different locations on various heat treated samples samples. The hardness increased nearly linear with various weight percentages of the nano SiC particulate.

Due to the application of high intensity ultrasonic waves, the acoustic streaming traps the nano particles into the melt effectively.

IV. MICROSTRUCTURES

The properties of the metal matrix nano composites depend on the distribution of the reinforcing particles and interface bonding between metal matrix and the dispersed particles. Samples with ultrasonic processing were examined with the optical microscope and SEM. Typical microstructures are shown in figures below**.**

The nanoparticles were well dispersed in the AA7075 matrix, although some microclusters remained in the matrix. The high-intensity ultrasonic waves generated strong cavitations and acoustic streaming effects. These transient cavitations can produce an implosive impact, strong enough to break up the clustered particles and disperse them uniformly in the liquid.

The optical micrograph and SEM images of MMNCs reinforced with 1.5wt% of nano SiC_p are presented in figures below. The optical images of the base metal in fig-3(a,b) show the grain boundaries clearly. With the optical microscopy no pores are observed. The grains in fig 3(a) are larger in size and that of MMNC's are smaller as seen in fig-3(b). The fig-4 shows images at higher magnification the grain boundaries are seen clearly. Fig.4a.shows SEM image of nano SiC with wt%1.0 and fig.4b. shows nano SiC with wt%1.5.The SEM images reveal that, there is uniform distribution of the nano SiC particles in the matrix (fig-5) and also small agglomerates of the powders and voids are seen at higher magnification. The overall microscopic analysis shows that there is good bonding between the matrix and the ceramic particulate, indicating uniform distribution of particles due to ultrasonic cavitation and grain boundaries are seen distinctly.

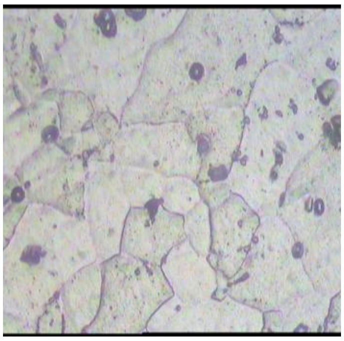

Fig.3a

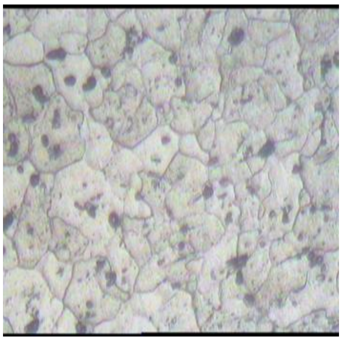

Fig.3b

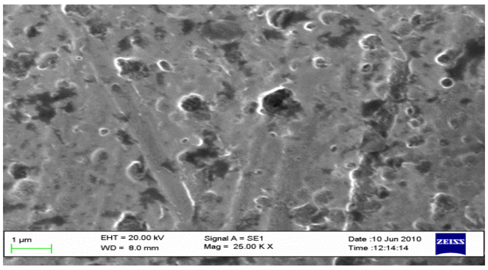

Fig.4a

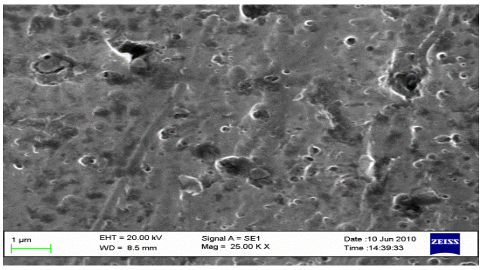

Fig4b

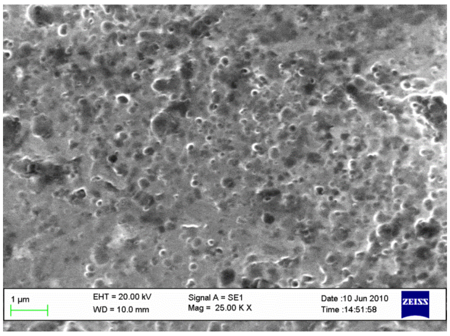

Fig.5

V. CONCLUSIONS

The aluminumAA7075 metal matrix nano composites were fabricated using mechanical stirring and ultrasonic cavitation methods. The effects of nano SiC particulate on microstructure and hardness are investigated.

a) The hardness of the aluminum MMNCs improved significantly by the addition of nano SiC particles nearly 10% compared with base metal.
b) The impact strength of the composites increased by75%.
c) The metal matrix nano composites have fine and more homogeneous microstructure with the increase of wt% of nano SiC_p content.
d) Ultrasonic nonlinear affects efficiently disperse nano particles into molten alloy by enhancing their wettability
e) Due to the Ultrasonic cavitation the hardness and impact strength have increased significantly in turn results in fine microstructures of the nanocomposites.

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