Investigations on Mechanical Properties of Nano Particulates (Al_2O_3/B_4C) Reinforced In Aluminium 7075 Matrix Composite

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Abstract- *Metal Matrix Nano Composites (MMNCs) with the addition of nano-particulate reinforcements can be of significance for automobile, aerospace and numerous applications due to their low density and good mechanical properties, better corrosion and wear resistance, low coefficient of thermal expansion as compared to conventional materials. The aim involved in designing the metal matrix composite material is to combine the desirable attributes of metals and ceramics.*

Present work is focused on the study of mechanical properties of Aluminium alloy (7075) with Al2O3 and B4C nano composite produced by Stir Casting technique and Ultrasonic Cavitation method. Different % age of reinforcement is used. By use of ultrasonic cavitation technique; to achieve a uniform dispersion of nano-particulate Al2O3 and B4C in molten aluminium alloy. Tensile test, Hardness test, Impact test performed on the samples obtained by the fabrication processes.

Micro structural study will be carried out through Scanning Electron Microscope (SEM) in order to know the distribution of Al2O3/B4C Nano particulates in Al alloy.

Keywords- Al7075, Ultrasonic Cavitation, Scanning Electron Microscope (SEM).Nano composite, reinforce particulates, metal matrix composite

I. INTRODUCTION

A composite material is made up of reinforcement embedded in matrix. A matrix holds the reinforcement to form the desired shape while the reinforcement phase improves the overall mechanical properties of the matrix. MMNCs are advanced engineering materials resulting from a combination of two or more materials in which tailored properties are achieved. Engineering MMCs consisting of continuous or discontinuous fibers or particulates in a metal or alloy possess combination of properties not achievable in monolithic. These properties could include high specific strength, specific stiffness, machinability, wear resistance and low coefficient of thermal expansion.

Aluininium oxide is the only chemical compound of aluminium and oxide with the chemical formula of Al_2O_3. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. It is used in abrasive, refractories, ceramics and numerous high performance applications. Some of the key properties of Al_2O_3 are: low density, high strength, low thermal expansion, high thermal conductivity, high hardness and high elastic modulus.

Boron carbide is a superior ceramic reinforcement material for AMCs than B_4C and Al_2O_3 due to its high hardness, low density, high strength, high wear and impact resistance, high melting point, low coefficient of thermal expansion and good chemical stability. The use of nano-sized B_4C particles to improve the mechanical properties of the AMCs is attractive because this approach could maintain good ductility and improve fracture toughness.

Many techniques are currently available to fabricate the metal matrix nano composites (MMNCs), such as mechanical alloying, high-energy ball milling, spray deposition, powder metallurgy, nano-sintering and various casting techniques. The powder metallurgy processing method cannot be used for bulk production of large and complex structural MMNCs components. The fabrication of MMNCs by powder metallurgy route is time-consuming, expensive and energy intensive. The liquid phase processing method can produce AMC parts with a uniform reinforcement distribution and complex shape, and this method offers better matrix-particle bonding and an easier control of the matrix structure. It is economical for bulk production. Uniform distribution and dispersion of nano-sized B_4C particles in molten aluminium is extremely difficult due to their large surface-to-volume ratio and poor wettability using a conventional mechanical stir casting method. The conventional mechanical stir casting method can be used to disperse micro-sized B_4C particles in molten aluminium without agglomeration and clustering.

Several researchers have proposed the ultrasonic cavitation technique to distribute and disperse ceramic nano- sized particles in an aluminium melt which enhances their wettability, the degassing of liquid metals and the dispersive effects for homogenizing. The liquid phase processing of MMNCs using high-intensity ultrasonic waves could be useful to disperse B_4C nano particles in molten aluminium because this process features transient cavitation and acoustic streaming. Acoustic cavitation is the formation and collapse of thousands of micro-bubbles in molten aluminium liquids under cyclic high intensity ultrasonic waves. The collapsing of micro-bubbles in molten aluminium produces transient micro-hot spots that can have pressures of approximately 1000 atm, temperatures above 5000^{o}C and heating and cooling rates exceeding 1010 K/s. Transient cavitation could result in strong impact coupling with the local high temperatures. It is sufficient to break up the clustered nano particles, disperse nano particles, refine grains, remove gas and homogenize the material.

In the present work, ultrasonic cavitation based solidification processing was utilized to fabricate Al_2O_3 and B_4C Nano particle- reinforced aluminium matrix composites by varying the concentration of Al_2O_3 and B4C. Nano-sized Al_2O_3 and B_4C particle-reinforced AMCs were produced by ultrasonic assisted cavitation method. Moreover, the mechanical and wear properties of AMCs reinforced with $Al_2O_3$and B_4C Nano particles were compared and analyzed.

II. MATERIALS AND METHODS

Pure aluminium was selected as a primary matrix material because it can be readily casted and has been widely used. Al_2O_3 and B_4C was used as a secondary reinforcement particle to fabricate the samples. The pure aluminium was purchased from M/s. BMC Enterprises, Bangalore, India. The size of the Al_2O_3 and B_4C particles was measured by SEM (SU1510) as 70 and 80 nm. B_4C nano particles were synthesized by ball milling the received B_4C powders in a high energy planetary ball mill. The ball milling operation was performed at room temperature under an argon gas atmosphere for 30 h.

The size of Al_2O_3 and B_4C particles was measured by SEM and Atomic Force Microscopy (AFM). To avoid the agglomeration of particles, a very small quantity of nano-sized Al_2O_3 and B_4C particle was mixed with 50 ml of acetone, and this mixture was placed in the ultrasonic sonicator for 10 min. The mixture was then characterized using SEM and AFM (XE70 park system). The final mean size of the Al_2O_3 and B_4C particles was 70 and 80 nm.

III. EXPERIMENTAL SETUP AND PROCEDURE

The metal matrix composite was prepared with a liquid metallurgical process using ultrasonic cavitation-assisted stir casting. Fig.1 shows the experimental setup for the ultrasonic cavitation-based fabrication of nano-sized Al_2O_3 and B_4C reinforced metal matrix nano composites. This setup consisted of an electric resistance heating furnace, ultrasonic probe and transducer, ultrasonic generator and inert gas protection system. A specially designed EN8 steel crucible with a capacity of 1.5 kg was used for melting and ultrasonic processing. An ultrasonic probe made of titanium was used to generate a frequency of 20 kHz with 2 kW power. The titanium probe was 20 mm in diameter and 200 mm long. The required amount of aluminium was melted in crucible at 750^{o}C in an electric resistance furnace for the ultrasonic processing of molten aluminium. The nano-sized Al_2O_3 and B_4C particles were added to the molten aluminium from the top of the crucible at proportions of 1,1.5 and 2% by weight. The mechanical stirrer was used for 10 min to achieve a primary distribution of nano particles in the molten aluminium.

Fig. 1 – Experimental setup for fabricating Al– Al_2O_3/B4C nano composites.

After mechanical stirring, the ultra-sonic probe was dipped into the molten aluminium to a depth of approximately 30 mm. The molten aluminium was processed with ultrasound for approximately 0.5 h to break up the clustered nano particles. After the ultrasonic processing, the crucible was quickly removed from the furnace, and the molten metal was poured into the die set mould. The mould was made up of mild steel, which was preheated to 500 8C before being filled with the molten aluminium. AMCs containing nano-sized Al_2O_3

and B_4C particles at proportions of 1, 1.5 and 2% were also fabricated by mechanical stirring in order to compare them with the nano composites.

Table.1 – Composition analysis (% Wt.) of Al7075 alloy

Constituent	Weight (%)	Constituent	Weight (%)
Cu	1.2-2.0	Mn	0.3
Si	0.4	Cr	0.18-0.28
Fe	0.5	Ti	0.1
Mg	2.1-2.9	Zn	5.1-6.1
Al		87.1-91.4	

Table.2 – Density and hardness of Al7075 alloy (non heat treated)

Density (g/cc)	2.918
Hardness (5 kg/25mm ball type)	164

The hardness of the composites was evaluated using a Brinell hardness testing machine. The applied load and dwell times for the hardness measurement were 5 kg and 5s, respectively. Each specimen was indented at an average of three times to determine the hardness. Tensile tests were carried out on a universal testing machine according to the ASTM standard E8. The tensile properties reported in this paper are the average of three tensile tests. The Charpy impact tests were performed on an impact testing machine according to the ASTM standard E23.

IV. RESULTS AND DISCUSSIONS

A. Tensile test:

From Table.3, it is clearly evident that the material behaves as brittle as when the % wt. increases beyond 1.5%. but upto 1% wt. it yields better yield strength (YS) and UTS.

Table.3 – Comparison the tensile test analysis of Al7075 alloy with reinforcements at different % wt.

Weight% of reinforcement (nano size)	Yield strength(MPa)	Ultimate tensile strength(MPa)	Elongation in 25 mm GL (%)
0% of Al_2O_3	95	107	2.00
0.5% of Al_2O_3	116	151	1.00
1 % of Al_2O_3	176	196	1.00
1.5% of Al_2O_3	Ultimate tensile strength(MPa) - 127		
2 % of Al_2O_3	Ultimate tensile strength(MPa) - 63		
0.5 % of B_4C	125	170	1.00
1 % of B_4C	Ultimate tensile strength(MPa) - 184		
1.5 % of B_4C	Ultimate tensile strength(MPa) - 139		
2 % of B_4C	Ultimate tensile strength(MPa) - 91		

B. Hardness test:

From Table.4, it is clearly evident that the hardness value is correspondingly much higher and increasing than the pure material when adding with increase weight percentage of reinforcements.

Table.4 – Comparison of hardness test results of Al7075 alloy with reinforcements at different % wt.

Weight% of reinforcement (Nano size)	Observed value in BHN(5mm ball/250 kg load)	Average value	Standard deviation
0% of Al_2O_3	68,69,70	69	1
1 % of Al_2O_3	92,93,94	93	1
1.5 % of Al_2O_3	101,101,103	102	1.414
2 % of Al_2O_3	101,102,103	102	1
1% of B_4C	95,95,94	95	0.707
1.5 % of B_4C	110,109,111	110	1
2 % of B_4C	115,114,117	116	1.732

C. Impact test:

From Table.5, it is clearly evident that there is no change in impact test values adding the reinforcements in different % wt. due to particulate reinforcements.

Specimen size (mm) : 7.5 X 10 X 55

Notch Type : ‘V’

` Test temperature : $24^{\circ}C$

Table.5 – Comparison of Impact test (Charpy) results of Al7075 alloy with reinforcements at different % wt.

Weight% of reinforcement (Nano size)	Observed energy-Joules
0% of Al_2O_3	2
1 % of Al_2O_3	2
1.5 % of Al_2O_3	2
2 % of Al_2O_3	2
1 % of B_4C	2
1.5 % of B_4C	2
2 % of B_4C	2

D. Scanning Electron Microscope (SEM):

Scanning electron microscope images of different weight percentages (1% weight, 1.5% weight and 2% weight) of nano size B_4C andAl_2O_3 are shown in figure 2, to 7. The

scanning electron microscope studies of the fabricated composite confirmed the porosity, agglomeration, and homogeneous and non homogeneous distributions of boron carbide particles in the aluminium matrix and the presence of Al_2O_3 and B_4C.
$Al_2O_3$and B_4C

Figure 2 SEM image of 0.5&1% weight Al_2O_3

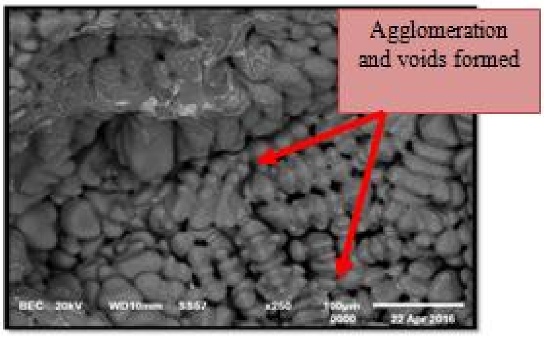

Figure 3 SEM image of 1.5% weight Al_2O_3

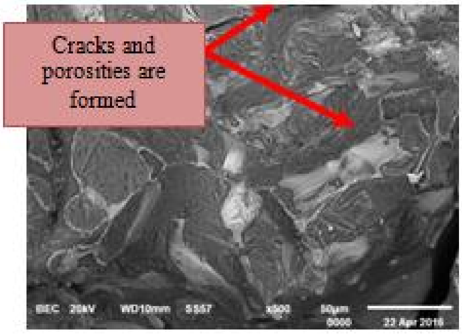

Figure 4 SEM image of 2% weight Al_2O_3

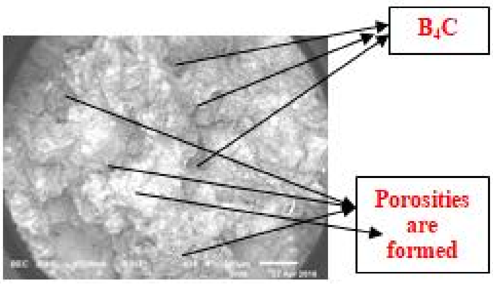

Figure 5 SEM image of 1% weight B_4C

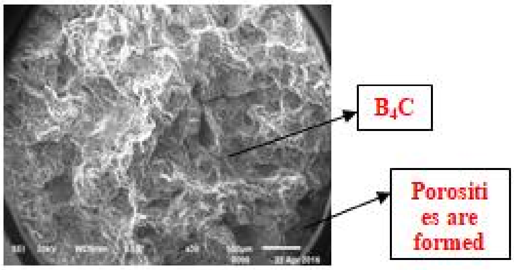

Figure 6 SEM image of 1.5 % weight B_4C

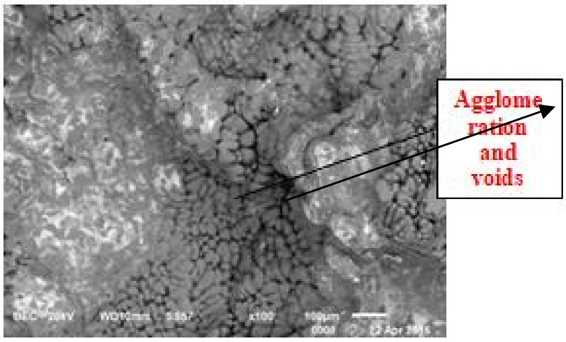

Figure 7.SEM image of 2% weight B_4C

V. CONCLUSIONS

The metal matrix nano composites are fabricated using mechanical stirring and ultrasonic cavitation methods. The effects of nano Al_2O_3 and B_4C dispersion on microstructure and mechanical properties are investigated using Scanning Electron Microscope (SEM).

The following points are concluded from the present investigations:

i. The results confirmed that Al-7075 reinforced with nano-particulate Al_2O_3/B_4C composites is superior than Al-7075 alloy compared with their tensile strength, hardness.
ii. It is found that elongation tends to decrease with increasing particles wt. Percentage which confirms that Al_2O_3/B_4C addition increases brittleness.
iii. Dispersion of Al_2O_3/B_4C particles in aluminium matrix increases improves the hardness of the material.
iv. The reinforcement of 0.5 and 1% weight of ($A1_2O_3$ / B_4C) nano size particles to the Aluminium 7075 matrix has led to improved mechanical properties (hardness, yield strength, Ultimate tensile strength) when compared to without reinforcement Aluminium 7075 alloy

v. Ultrasonic nonlinear affects efficiently disperse nano particles into molten aluminium alloy by enhancing their wettability.

vi. It appears from this study that UTS starts increases with increase in weight percentage of Al_2O_3 and B_4C, but Yield strength (YS) increases upto 1% wt of Al_2O_3 and B_4C exceeding 1% wt it starts behaves as brittle.

vii. From the observation of SEM image, there is uniform distribution of particles in the matrix when the weight percentage added upto 1%. Exceeding that there is a formation of cracks, porosity and agglomeration. Also a chance of brittle fracture in aluminium metal.

VI. ACKNOWLEDGMENT

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