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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. Designing the metal matrix composite material aims to combine the desirable attributes of metals and ceramics. The present work is focused on studying the mechanical properties of aluminium alloy (7075) with Al_2O_3 and B_4C nanocomposite produced using the stir casting technique and ultrasonic cavitation method. Different % age of reinforcement is used. An ultrasonic cavitation technique is used to achieve a uniform dispersion of nano-particulate Al_2O_3 and B_4C in molten aluminium alloy. Tensile, Hardness, and Impact tests were performed on the samples obtained by the fabrication processes. A structural study will be carried out through a Scanning Electron Microscope (SEM) to know the distribution of Al_2O_3/B_4C Nano particulates in Al alloy.

Keywords: *Al7075, Ultrasonic Cavitation, Scanning Electron Microscope (SEM), Nano Composite, Reinforce Particulates, Metal Matrix Composite*

1. Introduction

This research studies the mechanical properties of aluminium alloy (7075) with Al2O3 and B4C nanocomposite produced using the stir casting and ultrasonic cavitation methods. Different % age of reinforcement is used. The ultrasonic cavitation technique was used to achieve a uniform dispersion of nano-particulate Al_2O_3 and B_4C in molten aluminium alloy. A tensile test, Hardness test, and Impact test were performed on the samples obtained by the fabrication processes.

A Micro-structure study will be carried out through a scanning electron microscope (SEM) to determine the distribution of Al_2O_3/B_4C nano particulates in Al alloy (H.T. Nguyen et al. (2021)). Aluminum oxide is the only chemical compound of aluminum and oxide with the chemical formula of Al_2O_3. A high-temperature electro-chemical reaction of sand and carbon originally produced it. 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 to B_4C and Al_2O_3 due to its high hardness, low density, high strength, high wear, 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 enhance fracture toughness.

AMC parts have a uniform reinforcement distribution and complex shape, and this method offers better matrix-particle bonding and easier control of the matrix structure. It is economical for bulk production. Uniform distribution and dispersion of nano-sized B_4C particles in molten aluminum are complicated due to their large surface-to-volume ratio and poor wettability using a conventional mechanical stir casting method. The traditional mechanical stir casting can 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 aluminum melt, enhancing their wettability, degassing liquid metals, and dispersive effects for homogenizing. The liquid phase processing of MMNCs using high-intensity ultrasonic waves could help disperse B_4C nanoparticles in molten aluminum because this process features

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transient cavitation and acoustic streaming. Acoustic cavitation is the formation and collapse of thousands of micro-bubbles in molten aluminum liquids under cyclic high-intensity ultrasonic waves. The collapsing micro-bubbles in molten aluminum produce transient micro-hot spots with pressures of approximately 1000 atm, temperatures above 5000˚C, and heating and cooling rates exceeding 1010 K/s. Transient cavitation could have a substantial impact when coupled with high local temperatures. It is sufficient to break up the clustered nanoparticles, disperse, 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 B_4C. 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 Nanoparticles were compared and analyzed. This research's novelty lies in using a combination of nano-sized particles as reinforcement. This approach allows for a synergistic effect, where the nano-particles provide strength and toughness. The study also provides insights into how nanoparticles improve the mechanical properties of aluminum matrix 7075 composites. This research has potential applications in various industries, such as aerospace, automotive, and electronics, where lightweight and high-strength materials are required.

2. Materials And Methods

Pure aluminum was selected as a primary matrix material because it can be readily cast and has been widely used. Al_2O_3 and B_4C were used as secondary reinforcement particles to fabricate the samples. The pure aluminum 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 nanoparticles were synthesized by 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 minimal quantity of nano-sized Al_2O_3 and B_4C particles 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.

3. Experimental Setup And Procedure

The metal matrix composite was prepared using 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 nanocomposites. 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 aluminum was melted in a crucible at 750°C in an electric resistance furnace for the ultrasonic processing of molten aluminum. 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 nanoparticles in the molten aluminum.

After mechanical stirring, the ultra-sonic probe was dipped into the molten aluminum to a depth of approximately 30 mm. The molten aluminum was processed with ultrasound for approximately 0.5 h to break up the clustered nanoparticles. After the ultrasonic processing, the crucible was quickly removed from the furnace, and the molten metal was poured into the die-set mold. The mold was made of mild steel and preheated to 500 8C before being filled with molten aluminum. 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 to compare them with the nanocomposites.

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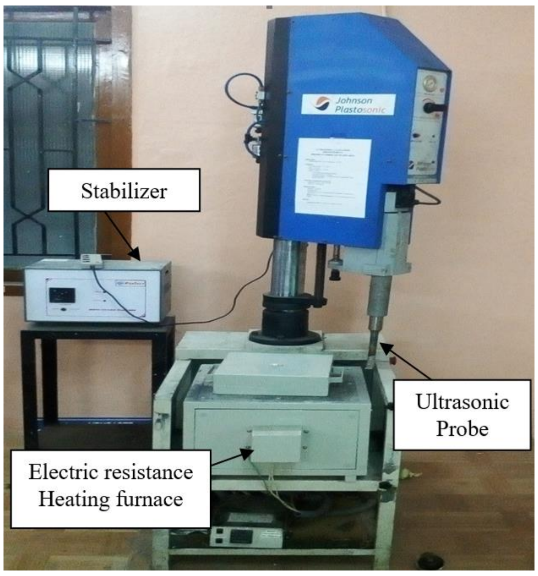

Fig. 1 Experimental setup for fabricating Al–Al_2O_3/B_4C nanocomposites.

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 an average of three times to determine the hardness. Tensile tests were performed on a universal machine using the ASTM standard E8. The average tensile properties reported in this paper are three tensile tests. The Charpy impact tests were performed on an impact testing machine according to the ASTM standard E23.

4. Results and Discussion

4.1. Tensile Test

From Table 3, it is evident that the material behaves as brittle as when the % wt. Increases beyond 1.5%. But up to 1% wt. It yields better yield strength (YS) and UTS.

Table 3 Comparison of 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		

4.2. Hardness Test

Table 4 shows that the hardness value is correspondingly much higher and increasing than the pure material when adding with increased 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)	Avg	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

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4.3. Impact Test

Table 5 shows no change in impact test values when 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◦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

4.4. Scanning Electron Microscope (SEM)

Scanning electron microscope images of different weight percentages (1% weight, 1.5% weight, and 2%) of nano-size B_4C and Al_2O_3 are shown in Figures 2 to 7. The scanning electron microscope studies of the fabricated composite confirmed the porosity, agglomeration, and homogeneous distributions of boron carbide particles in the aluminum matrix and the presence of Al_2O_3 and B_4C

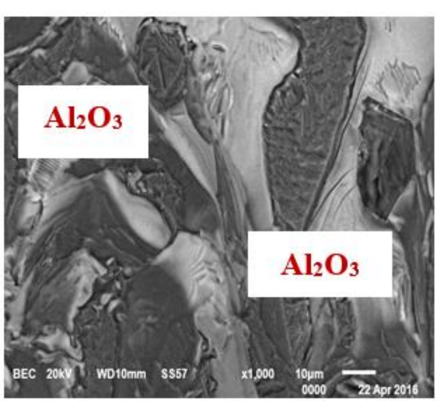

Fig. 2 SEM image of 0.5&1% weight Al_2O_3

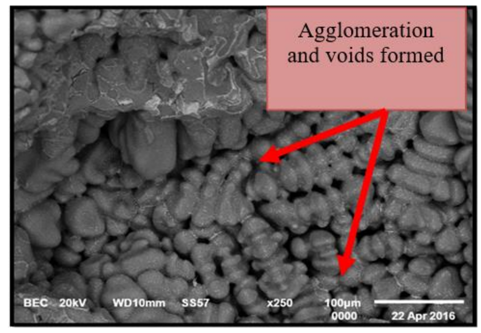

Figure 3 SEM image of 1.5% weight Al_2O_3

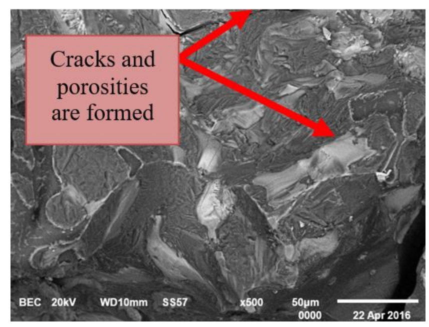

Fig. 4 SEM image of 2% weight Al_2O_3

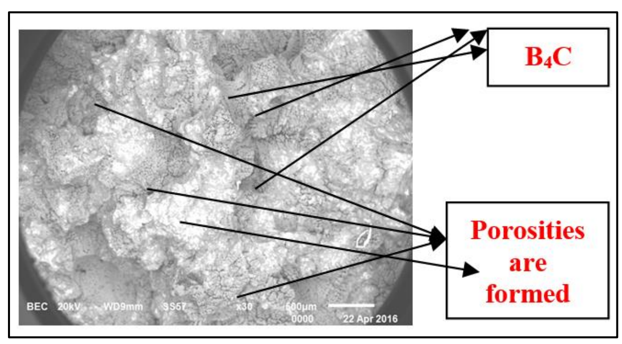

Fig. 5 SEM image of 1% weight B_4C

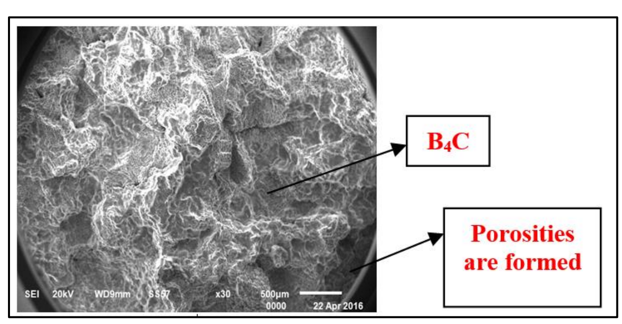

Fig. 6 SEM image of 1.5 % weight B_4C

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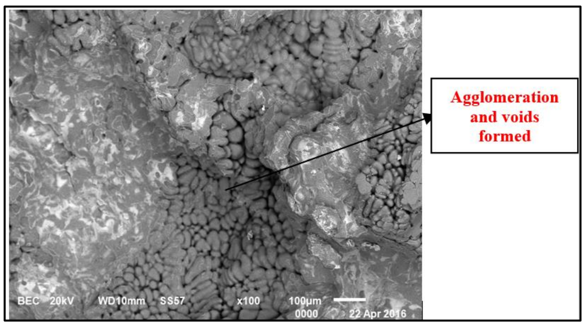

Fig. 7 SEM image of 2% weight B_4C

5. Conclusion

The metal matrix nanocomposites 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 a Scanning Electron Microscope (SEM).

The following points are concluded from the present investigations:

1. 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.
2. It is found that elongation tends to decrease with increasing particle weight percentage which confirms that Al_2O_3/B_4C addition increases brittleness.
3. Dispersion of Al_2O_3/B_4C particles in an aluminium matrix increases the material's hardness.
4. The reinforcement of 0.5 and 1% weight of (Al_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
5. Ultrasonic nonlinear effects efficiently disperse nanoparticles into a molten aluminum alloy by enhancing their wettability.
6. It appears from this study that UTS starts to increase with an increase in weight percentage of Al_2O_3 and B4C, but Yield strength (YS) increases up to 1% wt of Al_2O_3 and B_4C exceeding 1% wt it starts behaving as brittle.

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