Processing and Mechanical Characterization of Nano B₄C Particulates Reinforced Al₂₂₁₈ alloy Composites

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Abstract

In the current era of aerospace, automobile and other various industries, light weighed aluminium metal matrix nano composites plays a very major role. Nano metal matrix composites are composed of base material as metallic which is reinforced with ceramic particulate as reinforcement material. This paper consists of the preparation of nano composites by stir casting process by the addition of nano B₄C particulates into the Al₂₂₁₈ matrix by varying different weight percentages of 2% and 4% at a temperature of 730°C-750°C. Further once the nano composites are prepared, these are subjected to characterization, the SEM revealed that there was good uniform distribution of nano particles in the aluminum by exhibiting a good bonding with matrix and EDS confirmed the presence of B and C elements. Different mechanical properties were conducted like hardness, ultimate tensile strength and yield strength, which revealed that there was an increase the mechanical properties than compared to the base metal.

Key Words: Al₂₂₁₈ Alloy, nano B₄C, Stir casting, Nano composites, mechanical properties

1. Introduction

Nano metal matrix composites play a vital role in the current and modern technology. Usually micro ceramic particles are picked up for better yield and ultimate strength of the metal. But however the ductility of MMCs deteriorates with high ceramic particles absorption. So the nano particles reinforcement can significantly replaced in the place
of micro particles which enhance the mechanical strength of the matrix more effectively and thereby promoting the particle hardening mechanism than micron particles [1, 2].

Aluminum alloys as a matrix phase are widely used in aerospace, automobile and marine industries due to their various properties like low density, good mechanical properties, better corrosion resistance, and low thermal coefficient of expansion as compared to other conventional metals and alloys and also the cost of production is relatively low [3, 4]. Because of these characters they form a very strong and good contender in many of the applications [5]. However, the mechanical properties such as strength, elastic modulus and wear resistance are not enough for industrial applications; therefore, they are reinforced by various ceramic reinforcements such as Al₂O₃, SiC, graphite etc., [6, 7]. But nano B₄C ceramic particles as reinforcement made a remarkable trend and have recently been used for the better improvement of the mechanical and wear properties in Aluminum matrix composites by offering extremely high hardness, better strength, chemical stability and increase in thermal stability [8]. In addition, a limited work has been done on aluminum matrix composites by reinforcing with nano B₄C because of its high cost of raw material and poor wetting. B₄C is the third hardest material and it possesses an excellent hardness, low specific gravity, and high melting point therefore, which is a best suitable reinforcement material for nano metal matrix composites having density less than aluminum [9]. The Al–B₄C nano composites are used in different applications like bicycle frame, armor tanks, containment of nuclear waste, bullet proof vests, neutron absorber in nuclear power plant, Because the absorption of thermal neutrons produces heat and therefore the temperature of the material increases such that the Al–nano B₄C composites may experience long-term exposure for estimated temperatures [10].

Many different fabrication techniques are generally available for the fabrication of nano metal matrix composites, such as powder metallurgy, mechanical alloying, high-energy ball milling, nano-sintering, spray deposition, and variety of casting techniques [11]. Nevertheless mechanical stir casting process by the formation of vortex method is one of the best technique because, it is relatively inexpensive and it can be used to disperse nano sized B₄C particles in molten aluminium without forming agglomeration and clustering by the addition of nano ceramic particles in steps of two stages into the molten matrix and obtaining a good wetting by the proper selection of parameters like stirring speed, time, temperature of molten metal, preheating temperature of the mould and ceramic particle along with uniform feed rate of the reinforcement [4]. Even though stir casting allows producing components in bulk at a low cost of production with different complex geometries, but there are some disadvantages with it such as porosity, blowholes and proper distribution of the nano ceramic reinforcing particles between the metal matrixes. Due to this the mechanical properties often leads to degradation. However this problem occurs when the volume fraction of the reinforcement is high in the ratio of composites.

The present research work is done by the preparation of nano metal matrix composites by the addition of nano B₄C in Al2218 melt at a temperature of 730°C-750°C by stir casting process. During the composite preparation the pre-heated mix containing of
nano B₄C particles and K₂TiF₆ flux was added into the melt to enhance wetting and incorporation of nano B₄C particles into molten melt of Al2218. Further the prepared nano composites were subjected to evaluation of mechanical properties for the better enhancement compared to base metal.

2. Experimental Details

2.1 Process parameters – Matrix and Reinforcement

Al2218 is a 2000 series aluminum alloy which as major content of copper along with magnesium and it is formulated as wrought product and used a primary matrix material. Among aluminium alloys, Al2218 is chosen because it as a low density of 2.8 g/cm³ and used in various applications like jet engines, structural and tubing due to its excellent machinability characteristics. Because of high content of copper and magnesium the materials becomes age hardenable with good strength, corrosion resistance and has good weldability. Table 1 illustrates the chemical composition of Al2218 alloy.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mg</th>
<th>Ni</th>
<th>Zn</th>
<th>Ti</th>
<th>Mn</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (%)</td>
<td>0.90</td>
<td>1.0</td>
<td>4.5</td>
<td>1.8</td>
<td>1.7</td>
<td>0.25</td>
<td>0.10</td>
<td>0.20</td>
<td>Bal</td>
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</table>

For the present work the nano B₄C is used as secondary reinforcement particle which was procured from Reinste Nano Venture, Delhi, having a particle dia size of 500nm. The different physical characteristics like hard strength, catalyst support and as neutron absorber makes nano B₄C as a researchers and engineers choice for various applications by increasing mechanical and tribological properties. Aluminum is reinforced with nano B₄C because it a low density which is less than the matrix material which contributes to weigh saving and as high melting point up to 2350°C along with excellent chemical and thermal stability. Hence, nano B₄C reinforced aluminum matrix composite has expanded more attraction towards stir casting method with low coast.

2.2 Preparation of Nano Metal Matrix Composites

For the preparation of metal matrix nano composites stir casting technique is chosen because of less expensive and suitable for bulk production of components. The nano composites containing 2 and 4 wt. % of nano B₄C particulates were prepared from stir casting process technique. Initially the required amount of nano B₄C and the cast iron die are preheated to a temperature of 400°C. On the other part, the calculated amount of Al2218 was weighed and placed in a graphite crucible inside a electric furnace and heated to temperature of 750°C, so that the entire raw materials coverts into an molten
phase at a melting temperature of 660°C. After the complete melting of Al2218, the degassing powder known as Solid Hexa Chloro Ethane (C₂Cl₆) is introduced into the molten melt so that the unwanted adsorbed gases are forced out from the melt. The molten melt is disturbed by dipping a zirconium coated mechanical stirrer to form a clear vortex by stirring mechanism at a speed of 300rpm. Once the vortex is formed then the preheated nano ceramic particles along with the proper proportion ratio of K₂TiF₆ is introduced into the molten melt by a constant feed rate. At every each stage the continues stirring process is carried out before and after the pouring of mixture of nano B₄C and K₂TiF₆ to avoid clustering of particulates and to have uniform homogenous distribution of nano particulates in the melt. After continues stirring, the entire molten metal was poured into preheated cast iron die.

The prepared nano composites were machined as per the standards for characterization purpose. After confirming the uniform homogenous distribution of nano particles in the matrix by SEM and the presence of B and C elements by EDS, the mechanical behaviour of as cast Al2218 alloy and its nano composites were further evaluated as per ASTM standards.

3. Results and Discussions

3.1 Characterization by SEM and EDS

The Scanning Electron Microscope is used to examine the reinforcement pattern and the proper distribution of nano particles from the prepared nano composite. A piece of cut section was taken from the casted specimen and grinded using 220 grit SiC paper followed by 400, 600, 800 and 1000 grades of emery paper. Then the samples were mechanically polished and etched by Keller’s reagent (HCL+ HNO₃+HF+Water) to obtain the better contrast of the microstructure.

Figure 1a shows the scanning electron photographs of as cast Al2218 alloy. Similarly figure 1b showing 2 wt. % nano B₄C reinforced composites and figure 1c showing scanning electron photographs of 4 wt. % of nano B₄C particulates reinforced composites respectively. From the scanning electron photographs, it is revealed that there is uniform homogenous distribution of secondary phase of nano particulates in the Al2218 alloy matrix without any agglomeration. It is also observed that there is an excellent interfacial bonding between the nano B₄C and Al2218 alloy matrix, which further enhances the properties of Al2218 alloy. In the case of Al2218-4 wt. % nano B₄C composites, there are more particulates in the Al2218 matrix, which shows good castability and wettability of Al2218 alloy with ceramic reinforcements.
Figure 1: Scanning electron micrographs of (a) as cat Al2218 alloy (b) Al2218-2% B\textsubscript{4}C and (c) Al2218-4% B\textsubscript{4}C composites

Figure 2: Scanning electron micrographs of (a) as cat Al2218 alloy (b) Al2218-2% B\textsubscript{4}C and (c) Al2218-4% B\textsubscript{4}C composites
EDS analysis confirms the presence of Boron Carbide particulates in Al2218 alloy matrix in the form of B and C elements along with Al and Cu elements (figure 2).

3.2 Hardness Measurements

Figure 3 shows the effect of nano B₄C particulates on the hardness of Al2218 alloy. From the graphs, it is noted that nano particles reinforced composites showed more hardness strength as compared to the Al base matrix. Further, as weight percentage of nano B₄C increases from 0 to 4 %, in Al2218 composites, it is observed that hardness increased from 63.13 BHN to 85.66 BHN. This increase in hardness is mainly due to the presence of nano ceramic particulates in the matrix. These particulates act as the barrier for dislocations [12, 13].

The higher hardness values for composites containing finer nano B₄C particles can be attributed to the larger surface area of these particles in contact with the matrix alloy. Therefore, due to the co-efficient of thermal expansion mismatch between Al2218 and B₄C phases, higher dislocations densities are generated during processing [14].

3.3 Ultimate and Yield Strength

Figure 4 showing the effect of nano B₄C particulates on the tensile behavior of Al2218 alloy. From the graphs, it is noted that nano composites showed more ultimate and yield strength as compared to the Al2218 base matrix. Further, as weight percentage of nano B₄C increases from 2 to 4 %, in Al2218 composites, it is observed
that UTS increased from 208 MPa to 229 MPa, for base alloy it is found that 195 MPa. This increase in UTS and YS is mainly due to the presence of ceramic particulates in the matrix. These particulates act as the barrier for dislocations [15].

Further, the yield strength of Al2218-nano composites enhanced due to the presence of B₄C particulates. The mechanical properties of nano particulate reinforced MMCs are controlled by a complex interaction between the Al matrices and reinforcements. The addition of a reinforcing phase of different elastic properties induces strain concentration. In order to maintain the displacement compatibility across the interface when a far-field strain is applied, dislocations are generated at the composite interface [16]. Also, the difference in thermal expansion coefficients between the two phases necessitates the generation of dislocations to accommodate thermal strain on changing temperature.

3.4 Percentage Elongation

The improvement in UTS is, be that as it may, associated with a lessening in flexibility, which decreases as evidently appeared in figure 5. Expanding the wt. % of nano B₄C in the composite opposes the flowability of aluminum framework and diminishes the bendable aluminum compound network content which brings about the lessening of % prolongation of the composite [17].
4. Conclusion

In this research, nano $\text{B}_4\text{C}$-Al2218 composites have been fabricated by stir casting method by taking 2 and 4 wt. % of reinforcement. The microstructure, ultimate tensile strength, yield strength, percentage elongation of prepared samples is studied. The matrix is almost pore free and uniform distribution of nano particles, which is evident from SEM microphotographs. The EDS analysis confirms the presence of nano $\text{B}_4\text{C}$ particles in the Al alloy matrix. The mechanical properties of Al2218-2 and 4wt. % nano $\text{B}_4\text{C}$ composites are superior to those of unreinforced material. The ultimate tensile strength of Al2218 alloy is increased from 195 MPa to 229 MPa for 4 wt. % nano composites. Percentage elongation of nano $\text{B}_4\text{C}$ composites decreased as compared to the unreinforced Al2218 alloy.

REFERENCES


