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Investigating the Impact of Heat Treatment on Tensile Properties of Aluminum- B_4C Metal Matrix Mixtures

Anil Kumar B. N.[1], Prashanth Kumar.S.[2], Srikumar Birdar[3], Iranna Mallappa Biradar[4], Abrar Ahamad[5], Reddappa H. N[6], Abhinav[7]

[1,2,3] *Assistant Professor, Atria Institute of Technology, Bangalore, (VTU,Belagavi)*

[4] *Leturer BAZE University Abuja Nige*

[5] *Department of Mechanical Engineering, Vidya Vikas Institute of Technology, Bangalore, (VTU, Belagavi)*

[6] *Department of Mechanical Engineering, Bangalore Institute of Technology, Bangalore, (VTU, Belagavi)*

[7] *Assistant Professor, Department of Mechanical Engineering, Dayananda Sagar Academy of Technology and Management, Bangalore, (VTU, Belagavi)*

Abstract: In this investigation comparison study was made between heat-treated composites as well as untreated composites. In this investigation, an endeavor is made to determine the impact of heat treatment on the tensile properties of Al6061-B_4C composites. Different composites are manufactured by varying weight percentages from 4 to 10 percent through the stir casting method. Artificial aging hardening is done for compounds for periods of 4, 6, 8, and 10 hours. Prepared composites are tested to determine the impact of the heat treatment method on the tensile strength of the metal matrix compounds. The investigation found that heat-treated composites exhibit superior tensile properties compared to untreated composites. A comparison study was made in this investigation between heat-treated composites and untreated composites.

Keywords: Stir casting process, Tensile strength, Heat treatment, Scanning electron microscope etc.

1. Introduction

Due to the growing need for components with greater stiffness and lower density, aluminum based matrix composites are being extensively employed in both the aerospace and non-aerospace industries. In the piston crown of traditional diesel engines, aluminum matrix composites have replaced nickel cast iron, resulting in a product that is more abrasive, lighter, and less expensive [1]. Aluminum-based composites are utilized as base plates for various electronic equipment, heat sinks in chip carrier multilayer boards, and high-speed integrated circuit packages for computers due to their small thermal expansion and conductivity. Automotive drive shafts, cylinder liners, and connecting rods are a few examples of these uses [2]. Aluminum matrix can be reinforced and improved by using Al_2O_3, TiB_2, B_4C, and other less dense, strong ceramic particles [3]. For the fabrication of MMCs, a variety of fabrication techniques are used, including methods like solid-state and fluid-state, deposition, and in-situ processes [4]. Of these, molten-state methods, particularly mixing casting, have an appealing economic stage in addition to a wide range of materials and processing conditions [5]. Old-style stir casting involves swirling a molten matrix with reinforcing material before pouring the mixture into permanent molds [6]. The stirring action in the mixing casting process improves the bonding between the reinforcement and matrix. MMC manufacturing is the main cause of problems with producing uniform particle dispersion, wettability, chemical interactions at the interface, and porosity [7]. Most research projects on the construction of aluminum-based MMCs have used SiC, Al_2O_3, and TiB_2 as reinforcing materials; however, the use of B_4C

particulates is relatively inadequate due to their high price and lesser wetting properties with aluminum below 1100 °C [8]. With a hardness of 3800 HV, B_4C is the third hardest substance, behind diamond and CBN. Additionally, its low specific density of 2.52 g/cc, low thermal conductivity of 35 W/mK, high stiffness of 445 GPa, and superior impact and wear resistance enable it to be employed in a wide range of applications, including nozzles, ballistic armor. There are several methods to make ceramic particles more wettable, such as pre-treatment, surface-active chemical application [10], which lowers surface tension, and interfacial force application [11]. The integration of B_4C reinforcement into melt is enhanced when Ti powder is applied to B_4C particles, as complex surface layers of TiB and TiC are generated [12] and the bonding of these interfacial products becomes more metallic. Higher mechanical properties in the composite material have been made possible by an additional casting method that involves the use of K_2TiF_6 halide salt to strengthen the binding between the matrix and reinforcement particles [13]. Additionally, when the melt is being churned, it may be challenging to disperse the reinforcing particles equally throughout the matrix. After soaking, the particles experience density variations that cause them to sink or float, resulting in a non-homogeneous dispersion that may lead to particle segregation and clustering at a particular site in the melt. Such an impact might lead to various microstructural defects such as holes, oxide inclusions, and interfacial reactions [14-15].

The gap in research lies in the need for further exploration of effective methods to overcome the challenge's associated with the incorporation of B_4C reinforcement into aluminum melts, particularly in achieving uniform dispersion and enhancing wetting properties at lower temperatures. Additionally, more studies are needed to investigate novel approaches for addressing microstructural defects and improving the overall mechanical properties of aluminum-based matrix composites, particularly those reinforced with B_4C particles.

2. Experimental Procedure

By condensing blending with two-phase extensions, B_4C particles were utilized to produce 6061Al compound composites containing 4 to 10 wt. % of B_4C in two-step increments. Tables 1 shows the chemical composition of the Al 6061 composition and Table 2 displays the chemical composition of B_4C reinforcement. The mixture were prepared in a graphite crucible, a quantity of 2 kg of 6061-Aluminum was heated to 750°C using additional heating arrangement. To interrupt the process and create turbulence, an agitator was used. Slag was removed from the liquid metal, and a 3g degassing tablet was then injected into the vortex. Eight and ten weight percentages of warmed boron carbide particles were introduced into the vortex at 800°C with mechanical mixing arrangement .The process was carried out for five minutes at 300 rpm. The liquid metal was then poured into a heated mold and allowed to cool to a temperature of 850°C. Fig. 1 and 2 show the casted specimen and the mixer that has been used to create the composites.

Table 1: Chemical composition of Aluminum 6061

Composition		Al	Mg	Si	Fe	Cu	Cr	Zn	Ti	Mn
% age Weight	Min	95.85	0.8	0.40	0.0	0.1	0.04	0.0	0.0	0.0
	Max	98.56	1.2	0.8	0.7	0.40	0.35	0.25	0.25	0.15

Table 2: Chemical composition of B_4C

Property	Value
Density ($g.cm^{-3}$)	2.52
Melting Point (°C)	2445

Hardness (Knoop 100 g) (kg.mm^{-2})	2900 - 3580
Fracture Toughness (MPa.m$^{-½}$)	2.9 - 3.7
Young's Modulus (GPa)	450 - 470
Electrical Conductivity (at 25 °C) (S)	140
Thermal Conductivity (at 25 °C) (W/m.K)	30 - 42
Thermal Expansion Co-eff. x10^{-6} (°C)	5
Thermal neutron capture cross section (barn)	600

Fig.1 Cast iron specimen

Fig. 2 Mixing arrangement

2.2 Test specimens and heat treatment

Test specimens are prepared according to ASTM E8 standards [16]. The heat treatment process begins with solutionizing at 530°C for a period of 2 hours, followed by ice quenching. Subsequently, artificial aging is carried out at 177°C for durations of 4, 6, 8, and 10 hours.

3. Results and Discussion

3.1 Tensile strength

Heat treatment has a greater impact on the developed composites. The tensile strength was found to be maximum for the heat-treated composites compared to the untreated ones. From the figures, it is evident that tensile strength increases with increasing artificial aging temperature and reaches a maximum at 10 hours. Additionally, this research revealed that tensile strength increases with an increase in reinforcement. However, as reinforcement increases, the ductility of the composites decreases. Fig. 4 to 8 illustrates the variation of tensile properties with and without the heat treatment process. Heat-treated composites exhibit increased tensile properties compared to untreated ones. The figures also indicate that ice-quenched compounds have higher tensile values compared to naturally quenched ones. Specifically, Fig. 4 demonstrates that the heat-treated base material exhibits higher tensile strength compared to the untreated base material, and ice quenching results in better tensile strength than natural aging. Tensile values increase with increasing artificial aging time. Figs. 5 to 8 show that increasing the weight percentage of reinforcement increases tensile strength, and heat-treated composites exhibit better tensile strength compared to untreated ones.

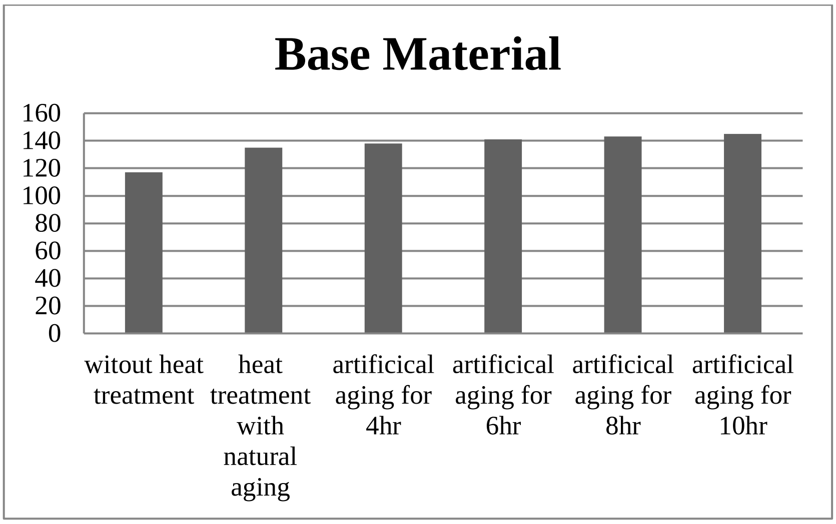


Fig. 4 Variation of tensile properties with & without heat treatment

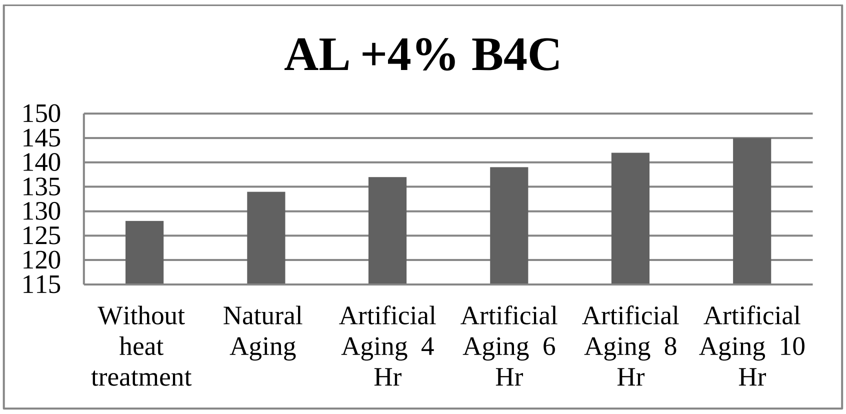


Fig.5 Variation of tensile properties with and without heat treatment at 4% B_4C

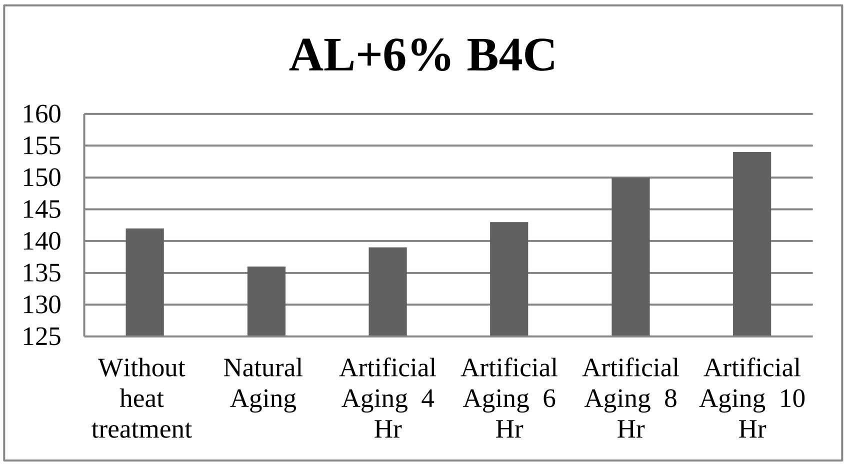


Fig.6 Variation of tensile properties with and without heat treatment at 6% B_4C

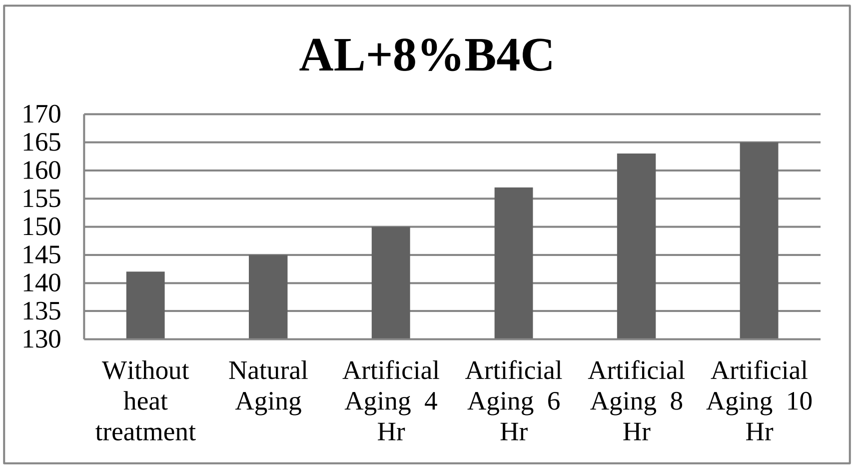


Fig.7 Variation of tensile properties with and without heat treatment at 8% B_4C

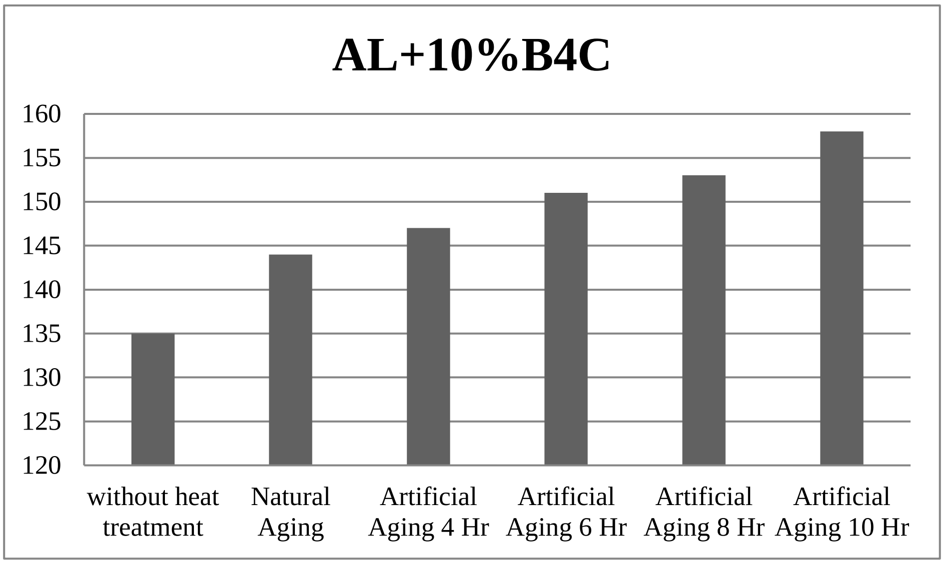


Fig.8 Variation of tensile properties with and without heat treatment at 10% B_4C

3.2 Scanning Electron Microscopy Analysis

Fig.9 (e) shows the SEM image of B_4C powder in its native phase. The cracked surfaces of the Al6061 alloy as-cast and the Al-8 weight percentage B_4C composites with a 40 µm size, both before and after heat treatment conditions, are shown in Fig. 9(a-d). The goal of the tensile fracture research is to determine how heat treatment affects the tensile fracture behaviors of composites reinforced with 8% B_4C. Figure shows that the matrix alloy exhibits greater dimples with voids; however, after heat treatment, the matrix alloy tends to exhibit smaller dimples and fewer vacancies, as depicted in Fig.b. When examined on a microscopic scale, the dimples in the heat-treated composite sample refer Fig. d display a rougher structure and smaller size compared to those in the compound created without heat treatment refer Fig. c Additionally, pockets of shallow dimples and microscopic voids mixed in with the rip ridges around the reinforcement are observed. This highlights the ductile nature of the material systems under study as a result of the heat treatment effect when compared to composites made without heat treatment.

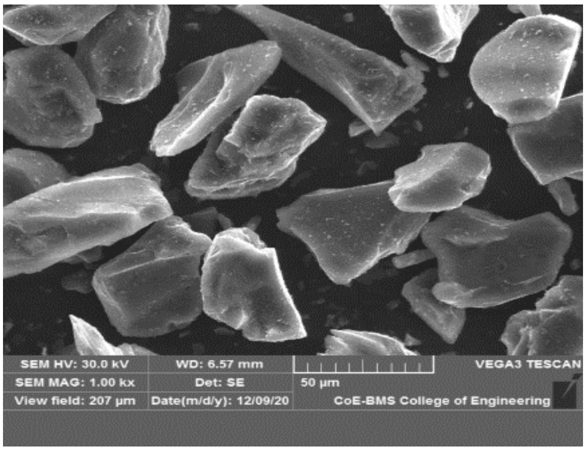
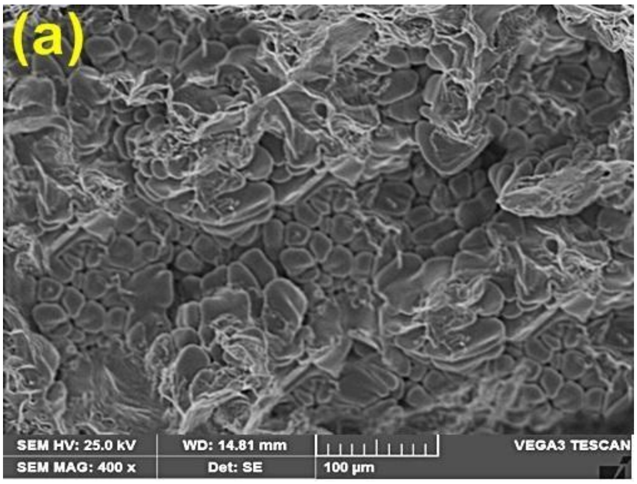
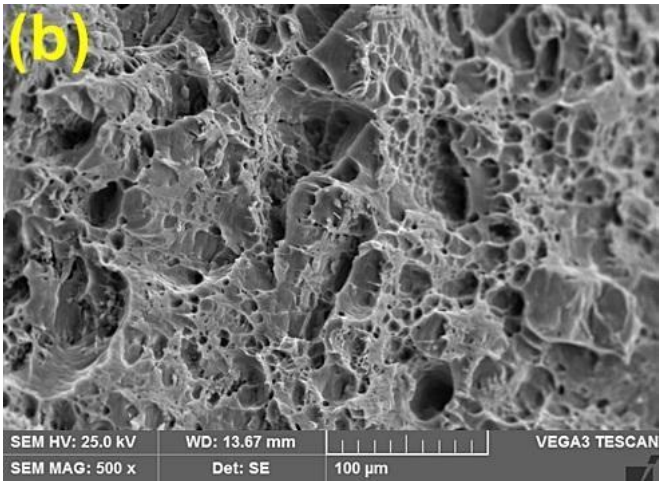


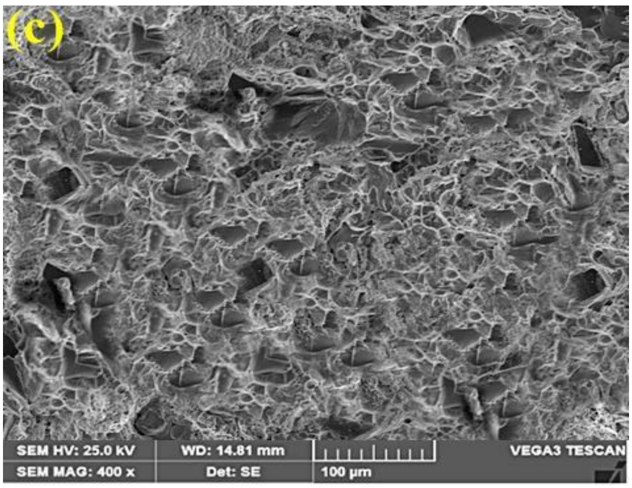
Fig.9 (e) SEM image of B_4C powder

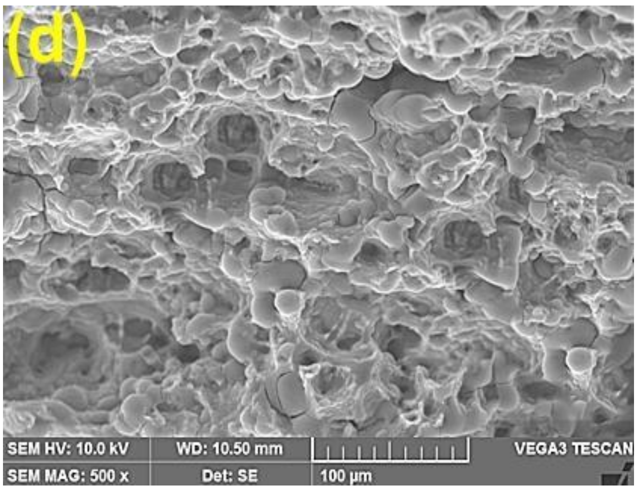




(a) as-cast Al6061 alloy-before heat treatment

(b) as-cast Al6061 alloy-after heat treatment(T-6)





(c) Al6061-8 wt.% B_4C-before heat treatment

(d) Al6061-8 wt.% B_4C- after heat

treatment (T-6)

Fig. 9 (a-d). depicts the fractographic images of (a-b) as-cast Al6061 before & after heat treatment and (c-d) Al6061-8 wt. % B_4C composite before & after heat treatment condition respectively

4. Conclusions

The important conclusions may be drawn as follows:

Al6061-B_4C composites were successfully cast using the liquid metallurgy route, and subsequent heat treatment was performed on both Al6061 alloy and Al6061-B_4C composites. The heat-treated composites exhibited superior tensile properties compared to untreated ones, with an increase in tensile strength of around 20%. Tensile strength was found to increase with aging time, and ice-quenched composites showed better tensile properties compared to naturally aged ones. Microscopic examination of the fracture surface of the heat-treated composite sample (Al6061-8 wt. % B_4C) revealed rougher and smaller dimples compared to the composite manufactured without heat treatment (Al6061-8 weight percent B_4C). Additionally, pockets of shallow dimples and microscopic voids mixed in with the rip ridges around the reinforcement were observed, characterizing the ductile nature of the material systems under study due to the heat treatment effect.

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