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Intermetallic-reinforced boron carbide (B_4C) composites produced through stir casting processing

E.Subba Rao[1], N.Ramanaiah[2]*
[1]Department of Mechanical Engineering, Loyala Institute of Technology and Management, Sattenapalli, Guntur, Andhra Pradesh, (INDIA)
[2]Department of Mechanical Engineering, A. U. College of Engineering (A), Andhra University, Visakhapatnam-530 003, Andhra Pradesh, (INDIA)
E-mail: n.rchetty1@gmail.com

ABSTRACT

The present study is aimed to evaluating the mechanical properties of aluminium metal matrix composite (AMMC). An effort is made to enhance the mechanical properties like hardness, tensile strength, yield strength, % of elongation of AMMCs by reinforcing AA6061 matrix with Boron carbide (B_4C) particles. AMMCs were made, AA6061 as matrix material and B_4C as reinforcement material, through stir casting method. AMMCs with varying percentage by different wt. %, 1%,2 %, 3%, 4%,5% B_4C were fabricated. A systematic study of the matrix metal and AMMCs were done to evaluate the mechanical properties (hardness, yield strength and tensile strength) in as cast and heat treated condition. It was observed that in comparison to the matrix metal, the precipitation kinetic was accelerated by adding the B_4C particles. It was noticed that, mechanical properties are increase with the increase in wt. % of the reinforcement up to 4% B_4C further addition there is a diminution in both the conditions (as cast and cold rolling followed by heat treatment condition). It was also thoughtout that 4% B_4C composite shows better mechanical (hardness, yield strength and tensile strength) properties and low % of elongation than all other compositions in both the conditions. Optical microscopy and Scanning electron micrographs were carried out to authenticate the mechanical properties of the matrix metal and AMMCs.

KEYWORDS

AA6061;
AMMC;
B_4C particles;
As casted;
Cold rolling followed by heat treatment;
Microstructure;
SEM.

INTRODUCTION

Composites are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties that remain separate and distinct within the finished structure. The bulk material forms the continuous phase that is the matrix (e.g.,metals, polymers)and the other acts as the discontinuous phase that is the reinforcement (e.g.,ceramics, fibers, whiskers, particulates). While the reinforcing material as usually carries the major amount of load &the matrix enables the load transfer by holding them together[1]. Composite materials are gaining wide spread acceptance due to their characteristics of behavior with their high strength to weight ratio[2]. The interest in material matrix composites (MMCs) is due to the relation of structure to properties such as specific stiffness or specific strength. Material matrix composites are being increasingly used in aerospace and automobile industries owing to their enhanced properties such as elastic modulus, hardness, tensile strength at room and elevated temperatures, wear resistance combined with significant weight savings over and reinforced alloys[3, 4]. The material matrix composite can be reinforced with particles and fibers. However, the biggest interest in composite materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their mechanical properties.

Mechanical properties were affected by selection of the volume fractions, size, and distribution of the reinforcing particles in the matrix[5].They are used more often, compared with the composite materials of other metals, due to the broad range of their properties and also due to the possibility of replacing the costly and heavy elements made from the traditionally used materials[6, 7]. Metal matrix composites reinforced with particles tend to offer enhancement of properties processed by conventional routes[8].

AMMC are the competent material in the industrial world. Due to its excellent mechanical properties it is widely used in aerospace, automobiles, marine etc.[9]. The aluminium matrix is getting strengthened when it is reinforced with the hard ceramic particles like B_4C, SiC, TiC and Al_2O_3 etc. Aluminium alloys are still the subjects of intense studies, as their low density gives additional advantages in several applications. These alloys have started to replace cost iron and bronze to manufacturewear resistance parts. The alloys primarily utilized today in construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircrafts.

Aluminum hybride metal matrix composites shows better improvement in hardness with the increasing in percentage of reinforcement where as decrease in density. (10). Mechanical properties (hardness, tensile strength and yield strength) of hybrid composites were increased with increasing Wt. % addition of reinforcements(11). Aluminium alloy AA6061 is available in a wide range of structural shapes, as well as sheet and plate products. This alloy has good weldable characteristics[12]. Aluminium is also ubiquitous element and one of the trace elements with moderate toxic effect on living organisms[13]. Hence the desire in the engineering community to develop a new material with greater mechanical properties, without much compromising on the strength to weight ratio led to the development of the metal matrix composites[14, 15]. Grain refiners (Sc, Tibor and Zr) containing AA4043 and AA5356 fillers added to AA6061 alloy was attributed to lower silicon/ magnesium segregation at grain boundaries[16]. The intermetallic particles are distributed uniformly in the composites and thus produced are fully dense with improved strength, which increases with the reinforcement content[17]

A limited research work has been reported on AMMCs reinforced with B_4C due to higher raw material cost and poor wetting. B_4C is a robust material having excellent chemical and thermal stability, high hardness (HV=30 Gpa) and low density(2.52g/cm3) and it is used for manufacturing bulletproof vests, armor tank etc. Hence, B_4C reinforced aluminium matrix composite has gained more attraction with low costing route[18].

MATERIALS and METHODS

Materials

AA6061 is used as matrix metal and Boron carbide(B_4C) powder of size 3-5 mesh as reinforcement material. The chemical composition of AA6061 and B_4C powder is shown in TABLE 1 and TABLE 2 respectively.

Experimental work

The simplest and the most cost effective method of liquid state fabrication is stir casting[19]. In this work stir casting technique is employed to fabricate, which is a liquid state metal in which a dispersed phase (reinforcement particulates) is mixed with a molten metal by means of stirring. The matrix AA6061 was melted at 700^0C in an electric furnace. At this high temperature magnesium ribbons were added into the molten alloy to increase the wetability.

TABLE 1 : Composition of AA6061 matrix metal

Ele	Cu	Mg	Si	Fe	Mn	Zn	Ti	Cr	Al
%	0.19	0.82	0.67	0.19	0.06	0.03	0.07	0.08	Rem

TABLE 2 : Composition of B_4C

Ele	B+C	B min	C max	B2O3	Fe	Si
%	96.5	75.3	21.2	0.72	o.35	0.21

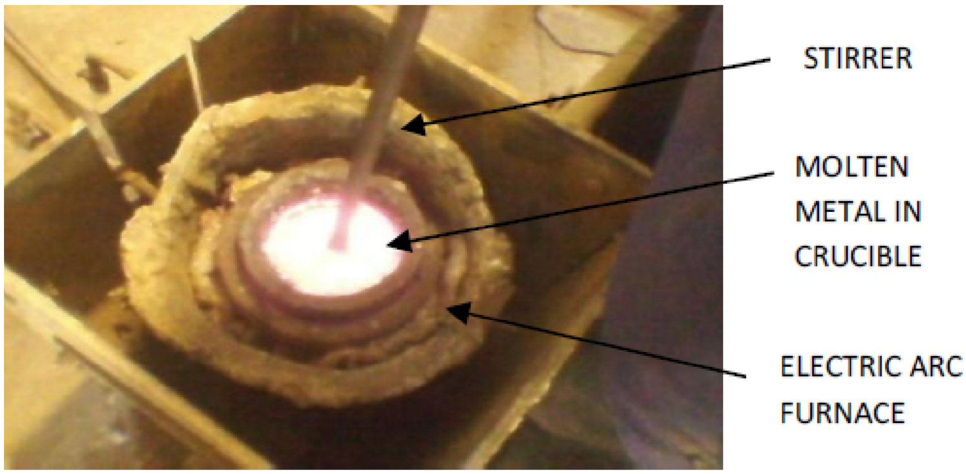

Figure 1 : Molten metal in the furnace

An appropriate amount(1% of the wet. Of base metal) of B_4C powder was preheated (350^0C) and then added slowly to the molten aluminium alloy. Simultaneously, the molten metal was stirred thoroughly at a constant speed of 300rpm with a stirrer for a period of 15 min. For a evenly dispersing B_4C particles in the molten aluminium alloy the high temperature AMMC was poured into the preheated (400^0C) cost iron mould. The same procedure was followed to get the AMMC 's of different wt. %,1%, 2%, 3%, 4% and 5% (having dimensions 300mmx300mmx6mm) the experimental setup is shown in Figure 1.

Treatment of AMMC

Fabricated composite was divided into equal parts of size 150x150x 6mm by mechanical cutting and are used for studying the mechanical properties in both the conditions (as cast and cold rolling followed by heat treatment).

As Cast

The fabricated specimens (150x150x6) were proposed to test for mechanical properties without any treatment.

Cold Rolling followed by heat treatment (CR & HT)

The composite plate thickness was reduced by 10% through rolling process using a rolling mill. AMMC plates were solutionized at 520^0C for 1Hr and water quenched then the specimen are artificially aged at 180^0C for a period of 12Hrs followed by air cooling.

Testing of AMMC

The fabricated specimens were proposed to test for mechanical properties like hardness, tensile strength, yield strength and % of elongation.

Hardness test

Hardness measurements were carried out on the matrix metal and composite samples by using standard Vickers hardness test machine. Vickers hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness.

Tensile testing

The specimens were machined to get dog boned structure as per ASTM E-8 standards. Test was carried out on a computerized UTM (TUE-C-600 Model

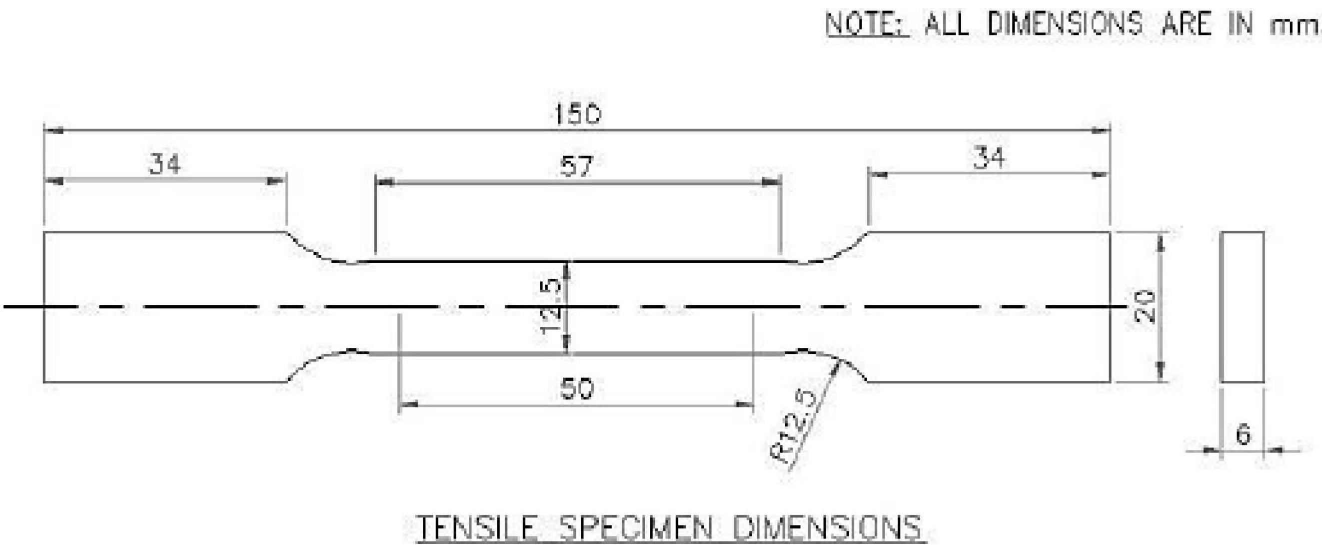

Figure 2 : Tensile test specimen as per ASTM –E8

TABLE 3 : Hardness (VHN) of the composite at various percentage of reinforcement (B_4C) in both the conditions (as cast and cold rolled followed by Heat treatment)

Condition $\%B_4C$	As cast	Cold rolled followed by Heat treated
1%	80	98
2%	83	104
3%	90	115
4%	103	118
5%	82	110

Machine). The tensile test specimens are as per ASTME-8 as shown in Figure 2

Microstructure of AMMC

Microscopic analysis of the matrix metal and composite samples were performed by optical microscopy and Scanning electron microscopy. An Image analyzer was used to examine the distribution of the reinforcement particles within the aluminum matrix. The mechanical properties of any particle rein-

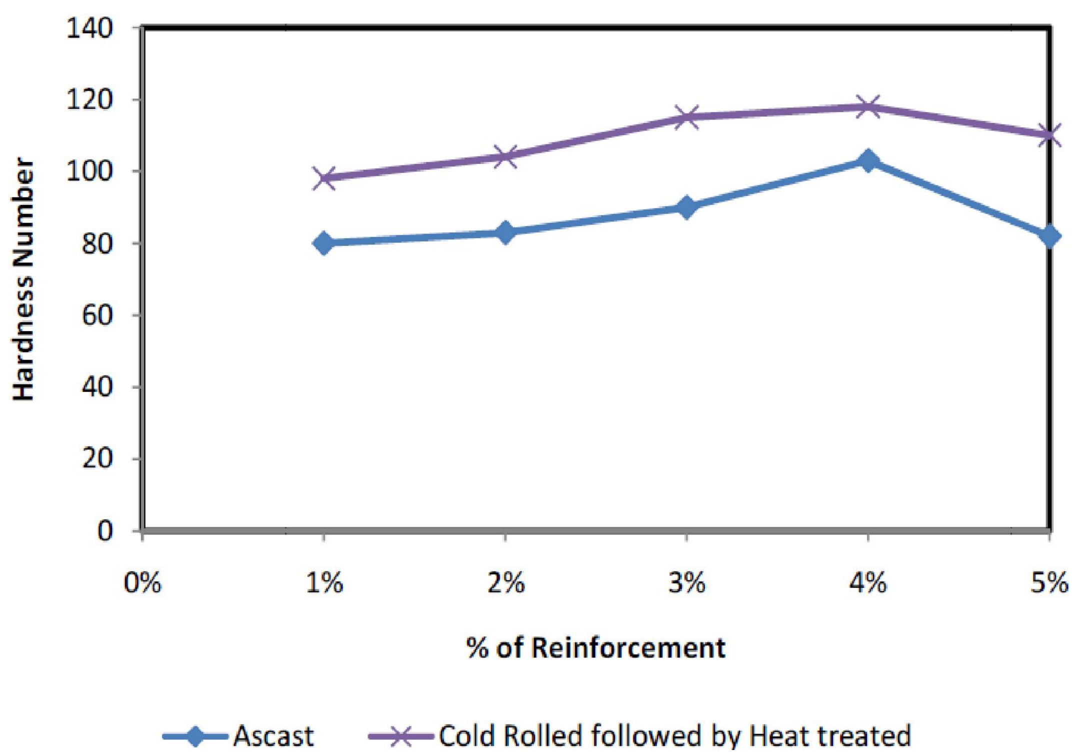

Figure 3 : Hardness (VHN) of the composite at various percentage of reinforcement(B_4C) in both the conditions (as cast and cold rolled followed by Heat treatment)

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forced metal matrix composites depend on the particle distribution, particle size, particle flaws, surface irregularities and particle matrix bonding. It is therefore, necessary to conduct a microscopic analysis on the new material in order to gain better understanding of its micro structural characteristics. The polished specimens were cleaned with acetone and etched with (Methanol (25ml) + Hydrochloric acid (25ml) + Nitric Acid (25ml) + Hydrofluoric acid 1 drop) solution.

RESULTS & DISCUSSIONS

Hardness

The tests revealed that, the hardness of the composite specimen is increased gradually with increase in the wt. % of B_4C powder incorporated in the metal matrix. The same thing was observed in hybrid composites (10 and 11). TABLE 3 shows hardness (VHN) of the composite at various percentage of reinforcement (B_4C) in both the conditions (as cast and cold rolled followed by Heat treatment). Figure 3 show the hardness all composites (1%, 2%, 3%, 4% & 5% of B_4C) in both the conditions. Cold rolled followed by Heat treated condition composite shows better hardness values than as cast condition and out of all conditions and compositions, 4% of B_4C composite shows better hardness.

Mechanical properties (tensile strength, yield strength & % of elongation)

The tests revealed that, the tensile strength of the composite specimen is increased gradually with increase in the wt. % of B_4C powder incorporated

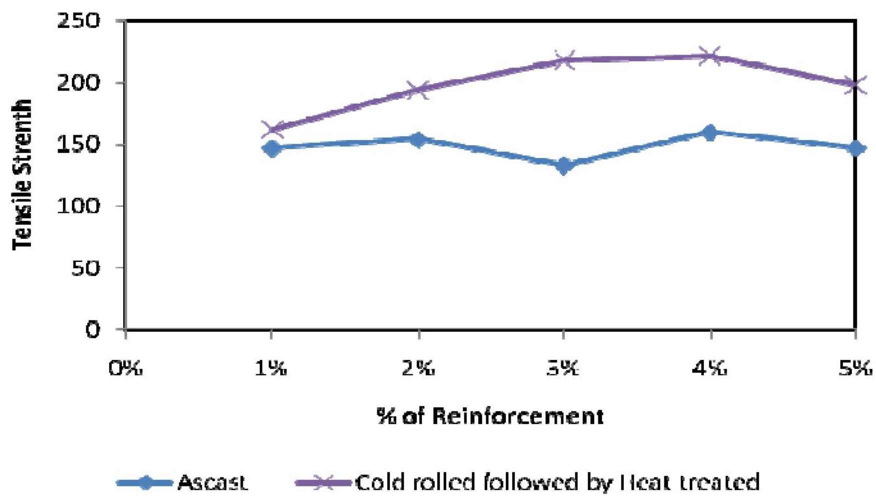

Figure 4 : Tensile strength of composites (1%, 2%, 3%, 4% & 5% of B_4C) in as cast and cold rolled followed by heat treatment condition

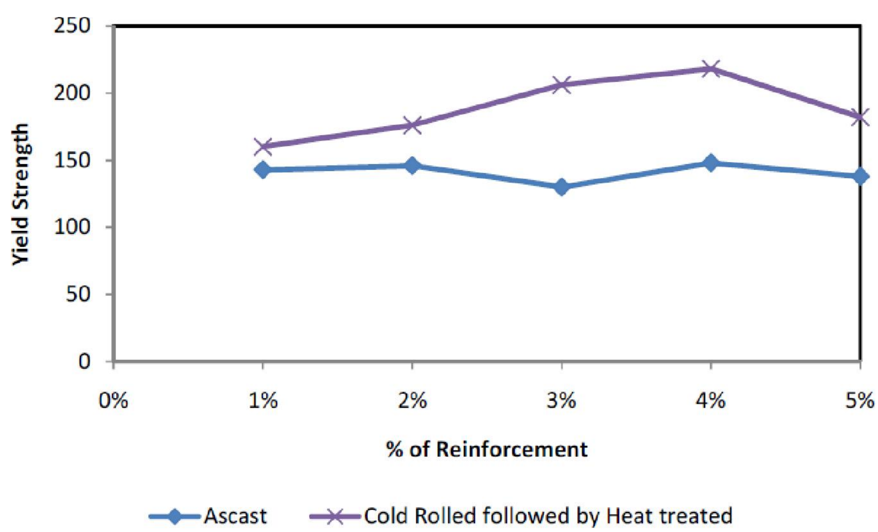

Figure 5 : Tensile strength of composites (1%, 2%, 3%, 4% & 5% of B_4C) in as cast and cold rolled followed by heat treatment condition

in the metal matrix. The same thing was observed in hybrid composites (11). Figure 4 shows the tensile strength of all composites (1%, 2%, 3%, 4% & 5% of B_4C) in as cast, and cold rolled followed by heat treat-

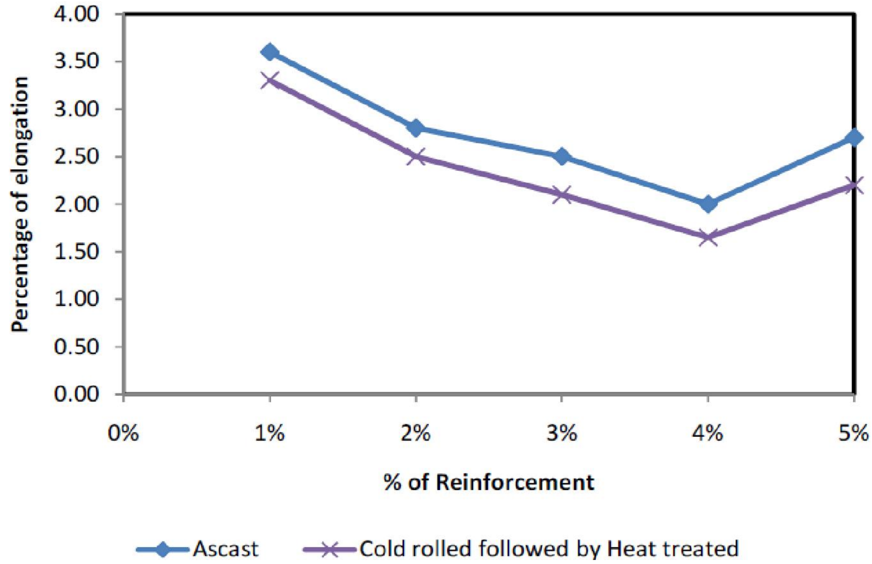

Figure 6 : The percentage of elongation of as casted and cold rolled followed by heat treated AMMCs

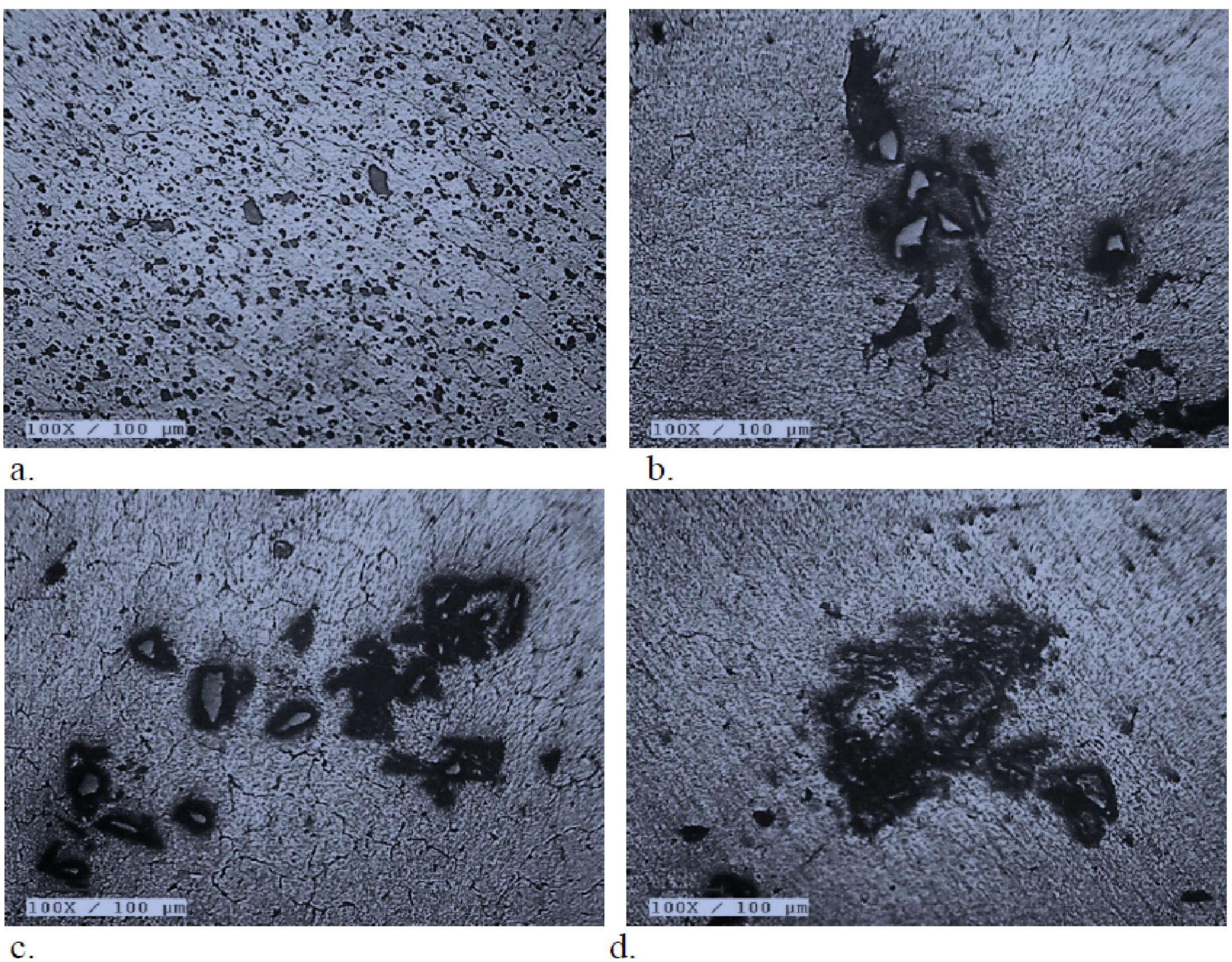

Figure 7 : Micrographs of (a) Matrix metal-T6 (b) 3% $_{B4}$C cast composite, (c) 4% $_{B4}$C cast composite and d. 5% $_{B4}$C cast composite

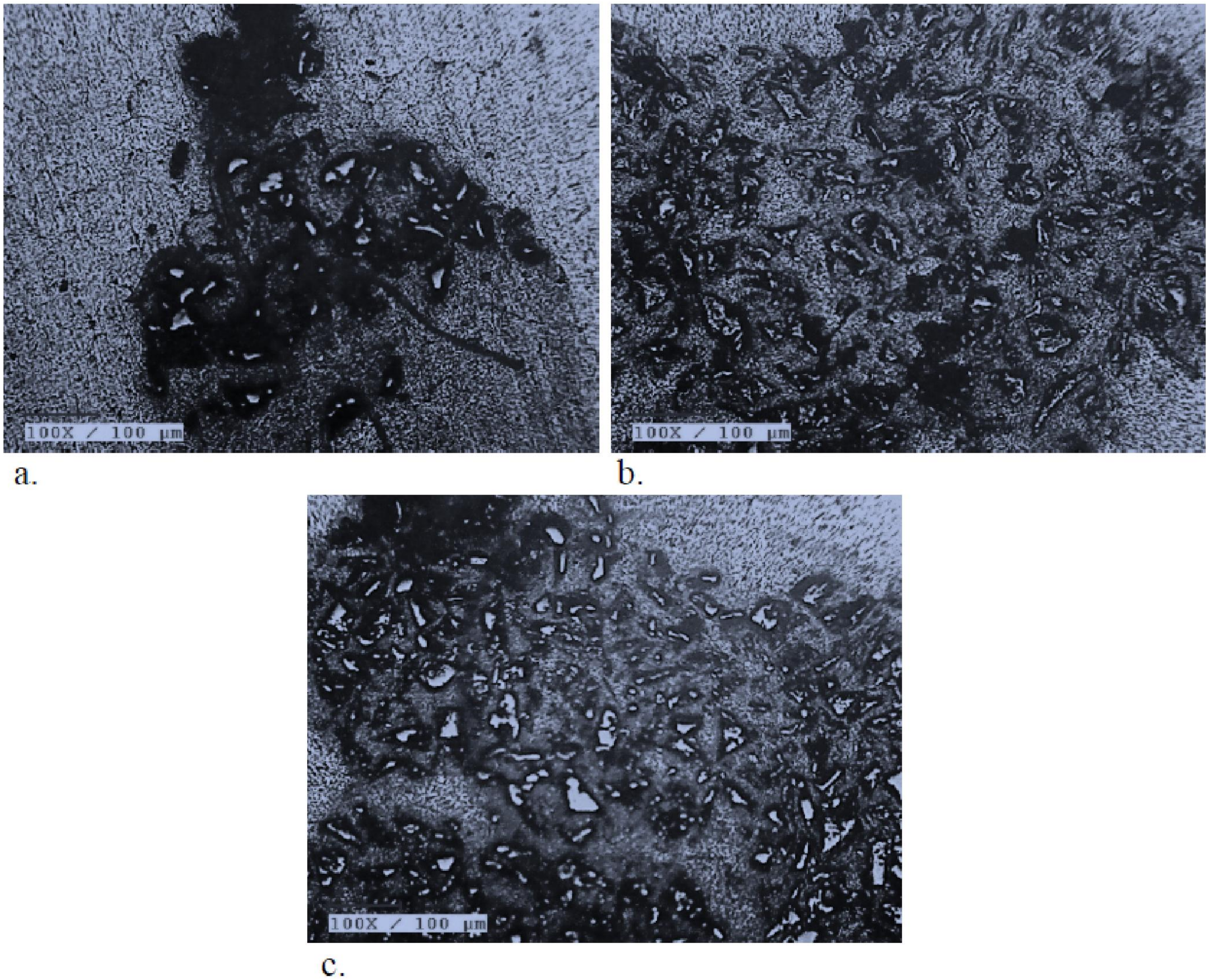

Figure 8 : Micrographs of (a) 3% B_4C cold rolling followed by heat treatment composite, (b) 4% B_4C cold rolling followed by heat treatment composite and (c) 5% B_4C cold rolling followed by heat treatment composite

ment condition. Out of all, the cold rolled followed by heat treatment condition composite shows better tensile strength values than all cast condition. 4% of B_4C composite made with cold rolling followed by heat treatment shows better mechanical properties than all other compositions. Similar trend was observed for yield strength (Figure 5).

Where as the percentage of elongation of the composites are decreased gradually with increase in the wt. % of B_4C powder incorporated in the metal matrix. Figure 6 shows the percentage of elongation of all composites (1%, 2%, 3%, 4% & 5% of B_4C) in both the conditions. Composites made with cold rolling followed by heat treatment shows the lower percentage of elongation values than as cast condition. Out of all 4% of B_4C Composite shows lowest % elongation than all other composites.

MICRO STRUCTURE

The morphology, density, type of reinforcing particles and its distribution have a major influence on the properties of particulate composites[1]. The specimens were prepared for microstructure analysis by thoroughly polishing and etching. Then the specimens were observed under an optical microscope and SEM for studying the microstructure.

Micrograph of the matrix metal (AA6061) in T6 temper is shown in the Figure 7a. It shows number of Mg_2Si particles are present in artificially aged (T6) alloy and shows columnar without reinforcement where as significant grain refinement was noticed when reinforced material

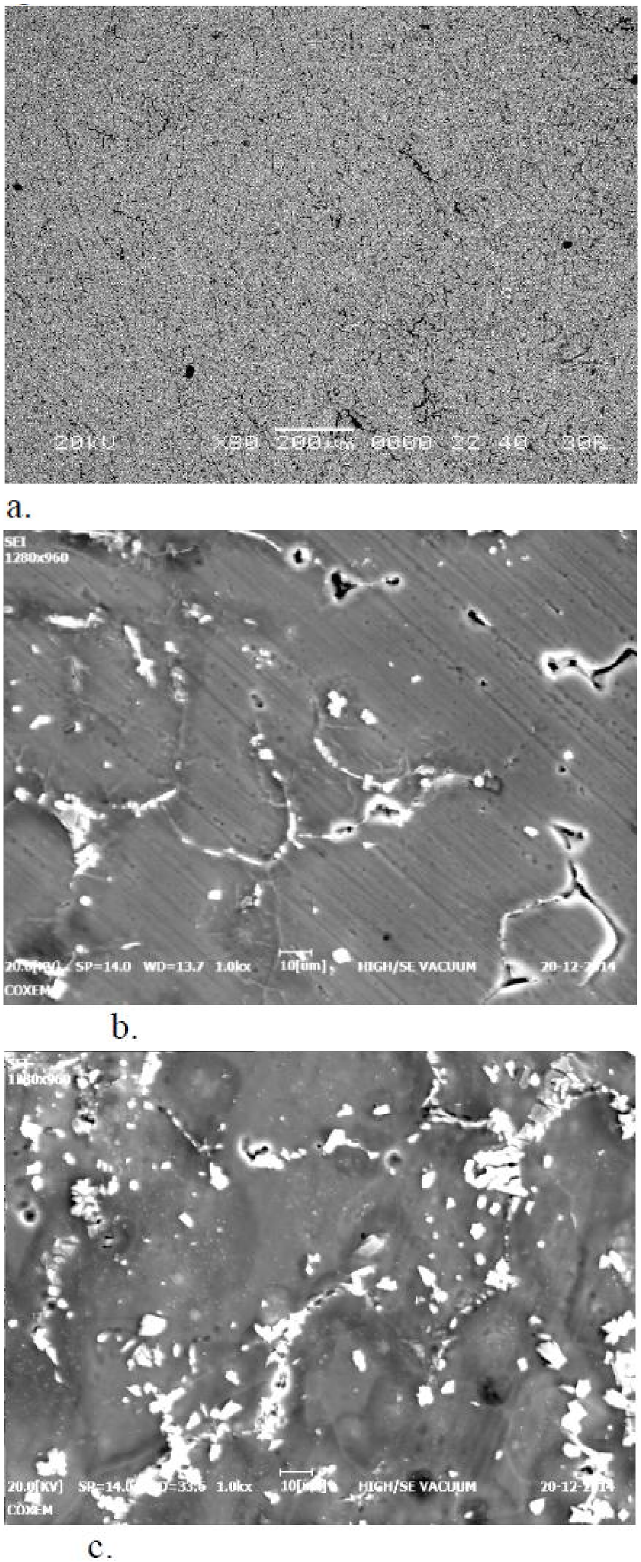

Figure 9 : SEM micrographs of (a) Matrix metal (b) As cast (AA6061+B_4C)composite and (c) Cold rolling followed by heat treated (AA6061+B_4C)composite

(B_4C) were added to the matrix metal (Figure 7b-e) in as cast condition.

Micrograph of the cold rolling followed by heat treatment composite is shown in the Figure 8a-c. It shows number of Mg_2Si and B_4C particles present and significant grain refinement was noticed when reinforced material (B_4C) were added to the matrix metal.

In Figure 9 b and c, small B_4C particles are clearly visible, while almost no fine B_4C_2 particles are visible in the cast composite (the particles appear white in the SE images due to charging of the nonconductive B_4C). Comparing the grain structure of the composite there is some grain refinement over the matrix material (Figure 9.a). While complete quantitative data were difficult to obtain from the matrix material, columner grains are clearly visible.

Conversely, the microstructure of the composite has much smaller grains. Figure 9.c. shows a fine with many smaller grains predominantly near B_4C particles. With the observed dispersion of fine B_4C particles throughout the matrix in the cold rolling followed by heat treatment, it is possible that the high number of potential heterogeneous nucleation sites could give rise to a further refined grain structure. However, in the as cast composite (Figure 9.b), there are large grains are observed.

CONCLUSIONS

The AA6061-B_4C composites of combinations 1%, 2%, 3%, 4% & 5% were produced through stir casting method. The mechanical properties of the composite of as cast and cold rolling followed by heat treatment were evaluated and compared matrix material and observed the distribution of reinforcements (precipitates) are homogenously distributed. The following conclusions are made from the study.

AA6061- B_4C composites AMMCs (AA6061/ B_4C) were successfully fabricated by stir casting method.

The mechanical properties of 4% B_4C cold rolling followed by heat treatment AMMC showed better value than all other composites.

Out of all the conditions, cold rolling followed by heat treatment of 4% of B_4C shows better yield and tensile strength but lower % of elongation.

Optical micrographs and SEM micrographs revealed that the B_4C particles were well distributed in the Aluminium matrix with cold rolling followed by heat treatment condition.

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