Influence of Nano B_4C Particulates on The Mechanical Characterization of Al7049 Alloy Composites

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Abstract

In the present study, the experimental results of the mechanical properties of Al7049-nano B_4C composites presented. The composites containing 3, 6 to 9 wt. % of nano B_4C in steps of 3 wt.% were prepared using liquid metallurgy route stir casting technique. For each composite, reinforcement particles were preheated to a temperature of 400˚C and then dispersed in steps of two into the vortex of molten Al7049 alloy to improve the wettability and distribution. Microstructural characterization was investigated by scanning electron microscopy (SEM) and elemental analysis was done by EDS. Tensile, compression and hardness tests were carried out in order to identify mechanical properties of composites. The results of microstructural study revealed distribution of nano B_4C particles. The results of this study revealed that as the weight percentage of nano B_4C particles were increased, there was significant increase in hardness, ultimate tensile strength, yield strength and compression strength of Al7049 alloy composites. Further, there was slight drop in the ductility of the Al7049 alloy composites as compared to the base. Tensile fractography was studies by using the SEM micrographs of tensile fractured specimens.

Key words: Al7049, Nano B_4C particles, Stir Casting, Microstructure, Mechanical Behaviour, Fractography

1. INTRODUCTION

Aluminium alloy nano-composite is useful in the aerospace, automobile, defence, and structural applications. The nano-composites have distinct properties. In the manufacturing process, different ceramic powders such as boron carbide, zirconia, aluminium oxide and silicon carbide are added to the lightweight aluminium alloy to enhance the mechanical properties.

Aluminium Matrix Composites (AMCs) are widely used in aircraft, automobiles, and marine field due to the good strength, light weight and low cost. Mechanical and wear behaviour can be observed in brakes, gears, valves, cams, bearings, clutches and other applications involving sliding contact or rolling contact. AMCs are one of the advanced engineering materials that have been developed for weight critical applications in the aerospace, and more recently in the automotive industries due to their excellent combination of high specific strength and better wear resistance [1]. Al composites have been developed recently with improved mechanical properties. Aluminum alloy 7049-T6 is widely utilized in aircraft, defense, automobiles and marine areas due to their good strength, light weight and better corrosion properties. But it exhibits inferior tribological properties in extensive usage. In addition, aluminum based composites become brittle by the addition of reinforcements such as SiC and Al_2O_3 ceramic particles. The reinforcement particles which have effect on the wear and mechanical properties have been identified as B_4C, SiC and TiC [2, 3].

Stir casting offers better matrix particle bonding due to stirring action of particles into the melts. The recent research studies reported that the homogeneous mixing and good wetting can be obtained by selecting appropriate processing parameters like stirring speed, time, temperature of molten metal, preheating temperature of mould and uniform federate of particles [4]. Among the manufacturing processes, the conventional stir casting is an attractive processing method for producing AMCs as it is relatively inexpensive and offers a wide selection of materials and processing conditions [5].

In most cases, hard ceramic particulates such as zirconia, alumina (Al2O3) and silicon carbide (SiC), have been introduced into aluminum-based matrix in order to increase the strength, stiffness, wear resistance, corrosion resistance, fatigue resistance and elevated temperature resistance. Among these reinforcements, SiC is chemically compatible with aluminum (Al) and forms an adequate bond with the matrix without developing inter-metallic phase and has other advantages such as excellent thermal conductivity, high machinability, good workability and low cost [6]. Wear rate of aluminum matrix composites reinforced with B_4C and SiC particles fabricated through the same route (pressure less infiltration method) were analyzed; the wear rate and friction coefficient of Al–B_4C was found to be lower than those of Al–SiC under the same conditions [7].

The aim of the present investigation is to evaluate the microstructure and mechanical behavior of Al7049 alloy reinforced with nano B_4C particles. The stir casting method is chosen for the manufacturing of AMCs. The effect of nano B_4C addition on the hardness, tensile and compression behavior of composite is investigated. The microstructures of the specimen are studied using scanning electron microscope (SEM) for the particle distribution and fractography analysis.

2. EXPERIMENTAL DETAILS

Materials

In the present study Al7049 is used as the matrix material, most of the applications in areas such as aerospace, automobile, marine make use of 7xxx series, aluminium zinc series alloys. Al7049 normally has 7.8% zinc. The theoretical density of Al7049 is taken as 2.84 g/cm^3.

Table 1: Chemical composition of Al7049 Alloy

Element	Si	Cu	Mg	Mn	Fe	Zn	Cr	Ti	Al
Wt. (%)	0.23	1.5	2.5	0.20	0.30	7.8	0.15	0.10	Balance

In the present work, nano B_4C particulates are used as the reinforcement materials, 500 nm particulates were used procured from Reinste Nano Ventures Ltd., Delhi. The density of boron carbide is lesser than the matrix material, which is 2.52 g/cm^3.

Methodology

The fabrication of Al7049-B_4C composites were carried out by liquid metallurgy route via stir casting technique. Calculated amount of the Al7049 alloy ingots are charged into the furnace for melting. The melting point of aluminium alloy is 660 °C. The melt superheated to a temperature of 750°C. The temperature was recorded using achrome-alumel thermocouple. The molten metal is then degassed using solid hexachloroethane (C_2Cl_6) for 3 min. A stainless-steel impeller coated with zirconium is used to stir the molten metal to create a vortex. The stirrer will be rotated at a speed of 300rpm and the depth of immersion of the impeller was 60 percent of the height of the molten metal from the surface of the melt. Further, the B_4C particulates are preheated in a furnace upto 400 °C will be introduced into the vortex. Stirring is continued until interface interactions between the reinforcement particulates and the matrix promotes wetting. Then, Al7049- 3 wt. % nano B_4C mixture are poured into permanent cast iron mold having dimensions 120mm length and 15mm diameter. Similarly, composites are prepared for varying weight percentage of nano B_4C particles.

Evaluation of Properties

The castings thus obtained were cut to appropriate size of 15 mm diameter and 5 mm thickness which is then subjected to different levels of polishing to get required sample piece for microstructure study. Initially, the sliced samples were polished with emery paper up to 1000grit size followed by polishing with Al_2O_3 suspension on a polishing disc using velvet cloth. This was followed by polishing with 0.3 microns diamond paste. The polished surface of the samples etched with Keller's reagent and finally subjected to microstructure study under the scanning electron microscope.

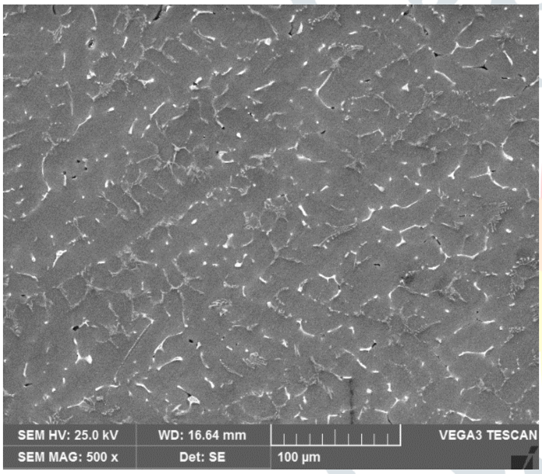
Hardness tests were performed on the polished surface of the specimens using Brinell hardness testing machine having a ball indenter of 5 mm diameter and 250 kg load for a dwell period of 30 seconds, five set of readings were taken at different places of the polished surface of the specimen and average was considered as per ASTM E10 [8]. The tensile and compression study was carried out on the cut specimens as per ASTM E8 and E9 standards using Electronic Universal Testing machine at room temperature to study properties like tensile strength, yield stress, percentage of elongation and compression strength.

RESULTS AND DISCUSSION

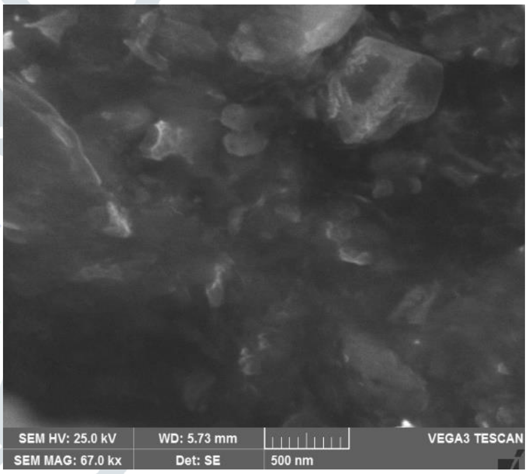
Microstructural Study

Figure 1a and b-d shows the SEM micrographs of as cast alloy Al7049 and the composites of 3, 6 and 9 wt. % of nano B_4C reinforced with Al7049 alloy composites. These two examined samples were chosen from the middle segment from the cylindrical specimens. The microstructure of as cast Al7049 alloy comprises of fine grains of aluminium solid solution with an enough dispersion of inter-metallic precipitates.

It additionally demonstrates the great holding between the framework and the fortification alongside the uniform homogenous circulation of nano estimated B_4C particulates with no agglomeration and bunching in the composites. This is essentially because of the viable mixing activity accomplished all through the expansion of the fortification by two phases. The nano particles everywhere throughout the grain limit of the lattice obstruct the grain improvement and oppose the separation development of grains amid stacking.



(a)



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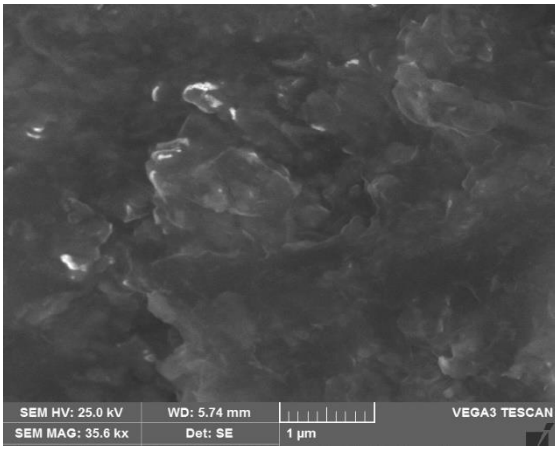

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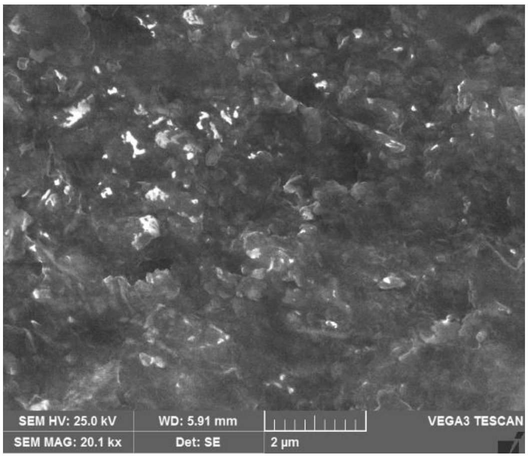


(d)

Fig. 1 Scanning electron micrographs of (a) as cast Al7049 alloy (b) Al7049-3 wt. % B_4C (c) Al7049-6 wt.% B_4C and (d) Al7049-9 wt.% B_4C composites

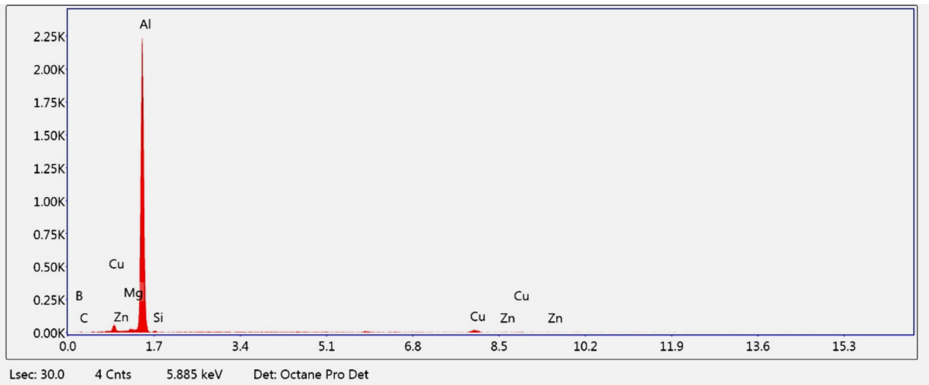


Fig. 2 Showing the energy dispersive spectrograph of Al7049-9 wt.% B_4C composites

From the figure 2 it is evident that nano B_4C particles are presented in the Al7049 alloy matrix in the form of B and C elements along with Al and Zn.

Hardness

Figure 3 shows the variation in hardness with the addition of 3, 6 and 9 wt. % of nano B_4C particulates to the Al7049 alloy. The hardness of a material is a mechanical parameter indicating the ability of resisting local plastic deformation. The hardness of Al-B_4C composite is found to increase with the addition of 3, 6 and 9 wt. % nano B_4C particulates. This increase is observed from 67.5 BHN to 98.3 BHN for Al composites. This can be credited basically to the nearness of harder carbide particles in the lattice, and furthermore the higher constraint to the localized matrix deformation during indentation as a result of the presence of harder phase [9]. Additionally, B_4C, as like other fortifications fortifies the matrix by making of high-density dislocations amid cooling to room temperature because of the distinction of coefficients of thermal expansion developments between the B_4C and grid Al7049 compound. Mismatch strains developed between the reinforcement and the matrix obstructs the movement of dislocations, resulting in improvement of the hardness of the composites.

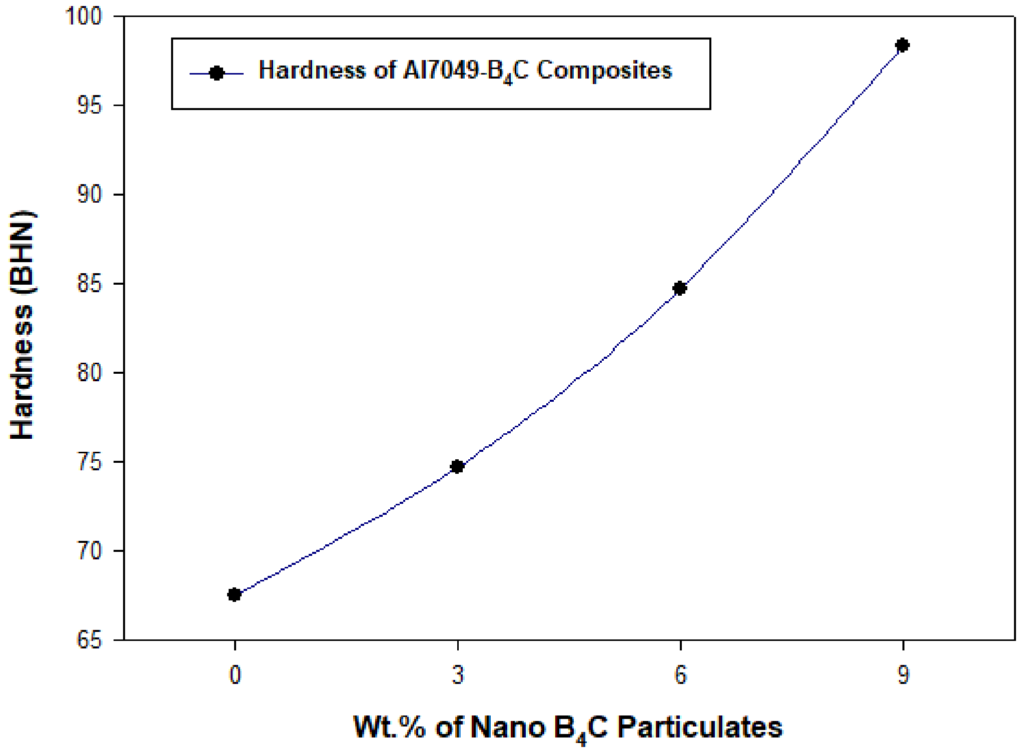


Fig. 3 Showing the hardness of Al7049 alloy-3, 6 and 9 wt.% B_4C composites

Ultimate Tensile Strength and Yield Strength

The plot of ultimate tensile strength (UTS) with 3, 6 and 9 wt. % of nano B_4C dispersoid in metal lattice composite has been introduced in figure 4. The deliberate estimations of UTS were plotted as a component of weight rate of nano boron carbide particles. There has been a change of 25.78% in UTS esteem when contrasted with base Al7049 alloy. The expansion in strength is credited because of legitimate contact between the framework and support materials. Better the grain estimate better is the hardness and quality of composites prompting to enhance the wear resistance moreover. The improvement in UTS is credited to the nearness of hard nano B_4C particulates, which confers quality to the framework amalgam, in this way giving improved rigidity [10]. The expansion of these particles may have offered ascend to huge lingering compressive anxiety created amid cementing because of contrast in coefficient of development between flexible matrix and brittle particles. The improvements of quality are likewise ascribed to closer packing of fortification and thus little inter particle spacing in the lattice.

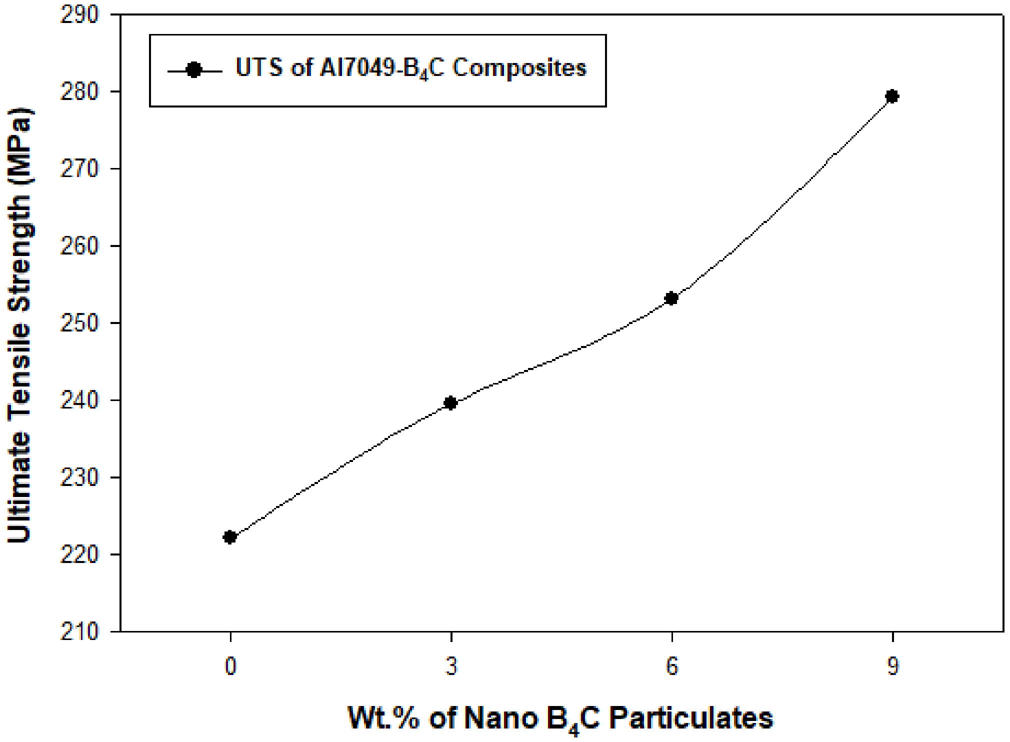


Fig. 4 Showing the ultimate tensile strength of Al7049 alloy-3, 6 and 9 wt.% B_4C composites

Figure 5 shows variation of yield strength (YS) of Al7049 alloy matrix with 3, 6 and 9 wt. % of nano B_4C particulate reinforced composite. It can be seen that by adding 3, 6 and 9 wt. % of B_4C particulates yield strength of the Al alloy increased from 177.4 MPa to 195.5 MPa, 205.7 MPa and 227.1 MPa respectively. This expansion in yield quality is in concurrence with the outcomes got by a few specialists, who have detailed that the quality of the molecule fortified composites is exceedingly reliant on the weight or volume division of the fortification. The expansion in YS of the composite is clearly because of nearness of hard B_4C particles which grant quality to the delicate aluminum network bringing about more prominent resistance of the composite against the connected ductile load [11]. On account of molecule strengthened composites, the scattered hard particles in the grid make limitation to the plastic stream, in this way giving upgraded quality to the composite.

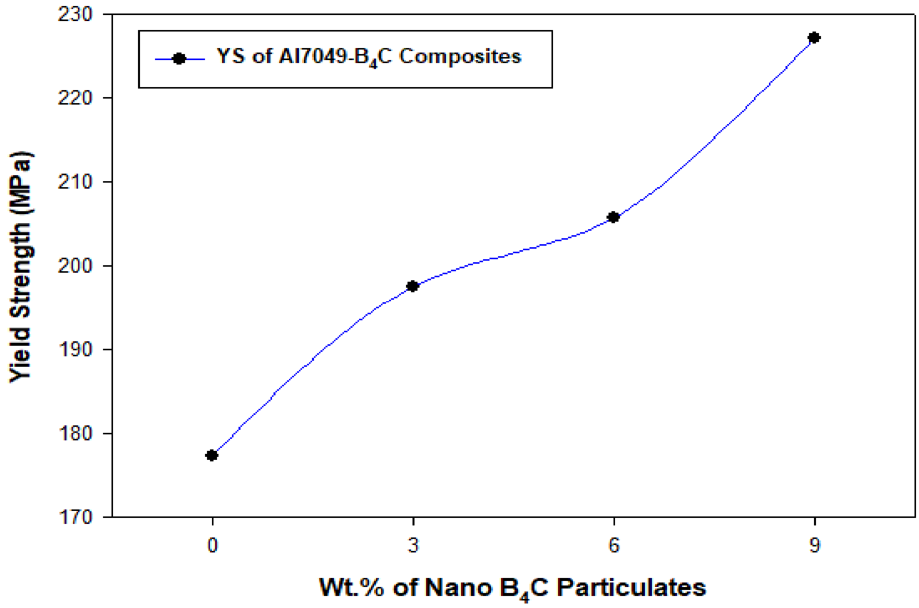


Fig. 5 Showing the yield strength of Al7049 alloy-3, 6 and 9 wt.% B_4C composites

Percentage Elongation

Figure 6 demonstrating the impact of nano B_4C content on the elongation (ductility) of the composites. It can be seen from the chart that the flexibility of the composites diminish essentially with the 3, 6 and 9 wt. % B_4C fortified composites. This diminishing in rate prolongation in correlation with the base amalgam is a most usually happening detriment in particulate fortified metal lattice composites [12]. The lessened pliability in composites can be ascribed to the nearness of B_4C particulates which may get broke and have sharp corners that make the composites inclined to restricted split start and proliferation.

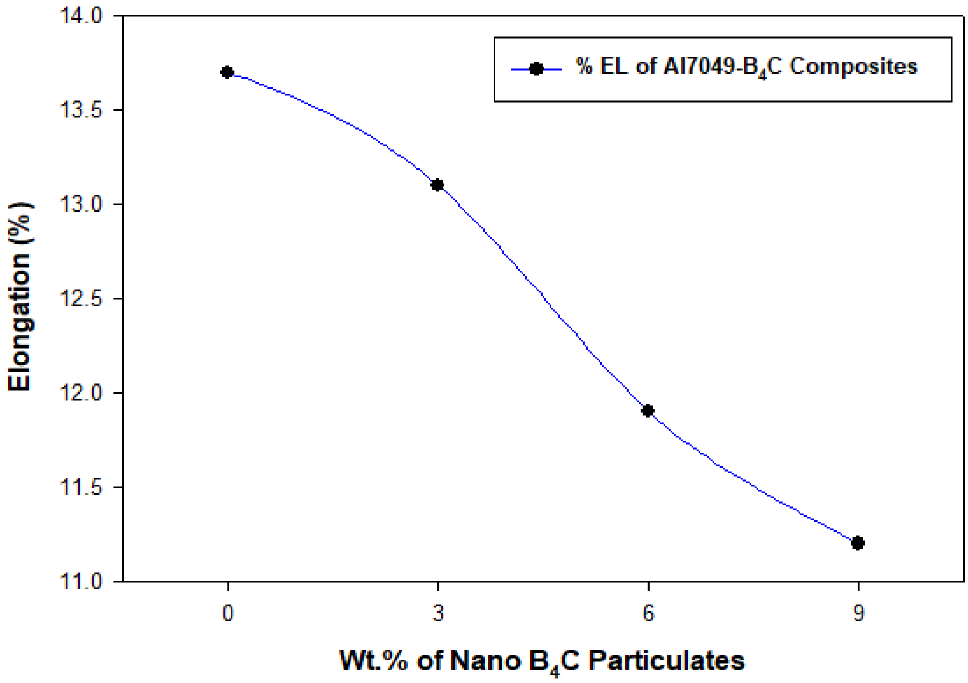


Fig. 6 Showing the percentage elongation of Al7049 alloy-3, 6 and 9 wt.% B_4C composites

Compression Strength

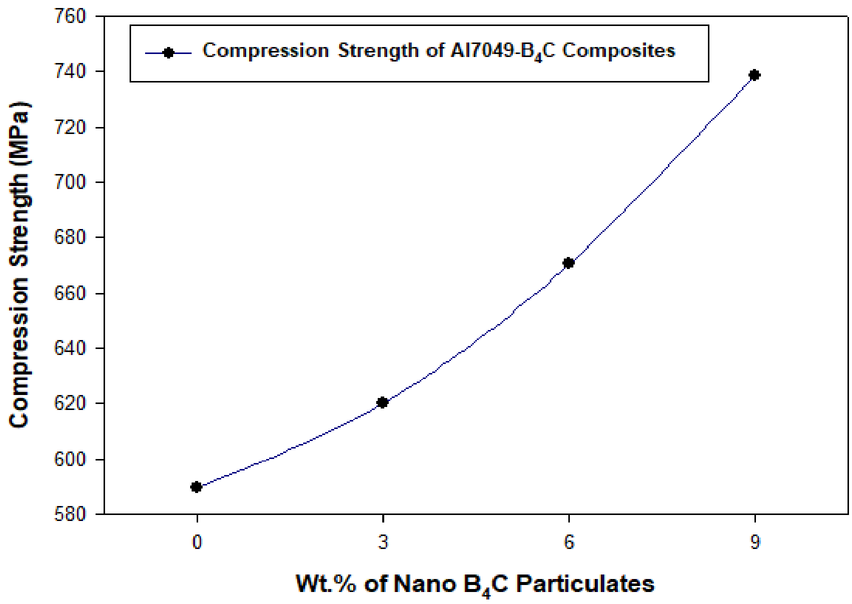
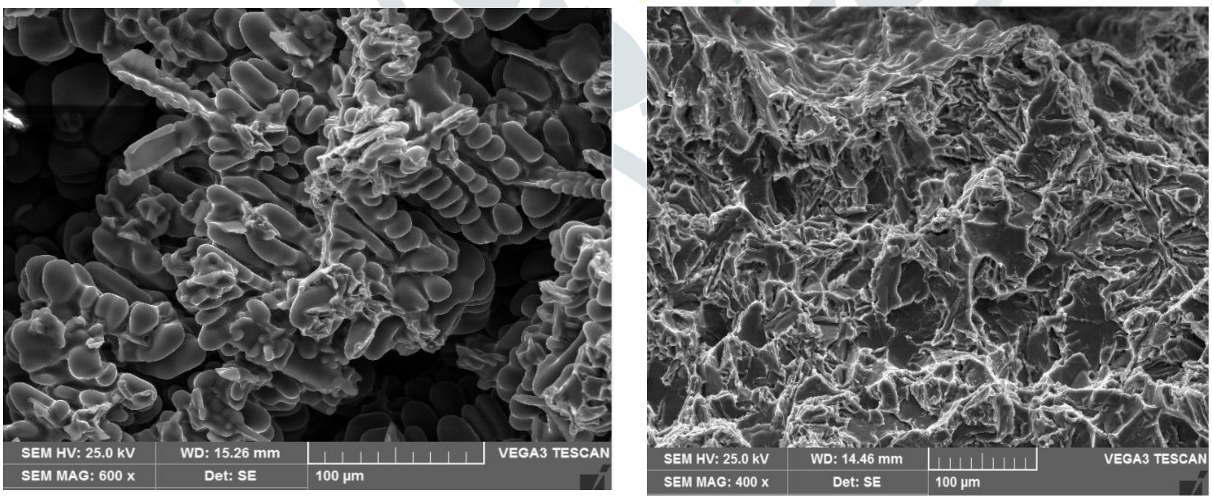


Fig. 7 Showing the compression of Al7049 alloy-3, 6 and 9 wt.% B_4C composites

Figure 7 shows variation of compression strength (YS) of Al7049 alloy matrix with 3, 6 and 9 wt. % of nano B_4C particulate reinforced composite. It can be seen that by adding 3, 6 and 9 wt. % of B_4C particulates compression strength of the Al alloy increased from 589.6 MPa to 620.1 MPa, 670.4 MPa and 738.5 MPa respectively. This increase in compression strength is mainly due to the presence of hard ceramic particles in the Al7049 alloy matrix.

Fracture Studies



(a) (b)

Fig. 8 Showing the tensile fractured specimens of (a) Al7049 alloy (b) Al7049-9 wt.% B_4C composites

Fracture mechanisms of as cast alloy and composite samples after tensile testing were studied by using SEM images of fracture surfaces (figure 8a-b). The as cast Al7049 alloy fracture mode is a ductile fracture mode as shown in figure 9-a, which has large number of dimple shaped structures, no crack can be seen.

Figure 9b shows that 9wt. % B_4C reinforced MMCs fracture structures have less ductile failure. During tensile test it is accepted that particle cracking along with matrix material fracture, de-bonding between the alumina particles and Al matrix alloy interface are some of the reasons for failure MMCs. Small voids observed in the case of 9 wt. % B_4C composites, fractured surfaces showed local stresses at the interfaces is more and so crack at reinforcement particles mechanism is observed.

CONCLUSIONS

In this research, Al7049-B_4C nano composites have been fabricated by stir casting method by taking 3, 6 and 9 wt. % of reinforcement. The microstructure, hardness, ultimate tensile strength, yield strength, percentage elongation, compression strength and fractography of prepared samples are 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 B_4C particles in the Al alloy matrix. The mechanical properties of Al7049-3, 6 and 9 wt. % nano B_4C composites are superior to those of unreinforced material. The fracture surface of the composite material consists of voids which formed by the strain localization. These voids were then coalesced during tensile loading, resulting in the formation of dimple appearance at the fracture surface.

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