Comparison of Tensile Properties of Varying Size Boron Carbide Particulates Reinforced Al7475 Alloy Composites

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Abstract

In the present work investigations have been made on effect of 37 and 88 micron sized B_4C particulates addition on the tensile mechanical behaviour of Al7475 alloy. Micro B_4C particulates of 37 and 88 microns were used as the reinforcements in the Al alloy matrix. Composites were prepared by using liquid melt method in steps of 2, 4, 6, 8 and 10 wt. % in the Al7475 alloy. Samples were tested for microstructural characterization by using scanning electron microscope and energy dispersive spectroscope. Tensile properties like ultimate tensile strength, yield strength and percentage elongation were evaluated as per ASTM standards. Scanning electron micro photographs revealed the uniform distribution of B_4C particulates in the Al7475 alloy and confirmed by EDS analysis. Further, ultimate tensile and yield strength of base matrix Al7475 alloy was enhanced with the addition of B_4C reinforcement and is more in the case of 37 micron size reinforced composites. There was slight reduction in ductility of composites in both cases.

Keywords: Al7475 Alloy, Micro B_4C, Melt Stirring, Microstructure, Tensile Behaviour

INTRODUCTION

Aluminium and its alloys have continued to maintain their mark as the matrix material most in demand for the development of Metal Matrix Composites (MMCs) [1-3]. This is primarily due to the broad spectrum of unique properties it offers at relatively low processing cost. Some of the attractive property combinations of Al based matrix composites are: high specific stiffness and strength, better high temperature properties, thermal conductivity, and low thermal expansion [4-5].

As a result of this, these materials are found to be used in mechanical components such as gears, cams, wheels, impellers, brakes, clutches conveyors, transmission belts, bushes and bearings [6]. In most of these services the components are subjected to tribological loading conditions.

There are several fabrication techniques available to manufacture MMC materials but there is no unique route in this respect. Due to the choice of material and reinforcement and types of reinforcement, the fabrication techniques can vary considerably. There are two types of fabrication methods available i) solid phase fabrication method includes diffusion bonding, hot rolling, extrusion, drawing, explosive welding, powder metallurgy route, and pneumatic impaction ii) liquid phase fabrication method includes liquid metal infiltration, squeeze casting, compo casting, pressure casting and spray co-deposition [7] The preparation of such Al based composites by melting and casting routes i.e. stir casting is by far the most economical one, but is associated with some inherent problems arising mainly from both the apparent non wettability of Al_2O_3, TiC, B_4C and graphite by liquid aluminium alloys [8] and the density differences between the two materials. Therefore, the introduction and retention of hard ceramic particles like B_4C, WC, Al_2O_3 and soft particles like graphite in the molten aluminium is extremely difficult. Poor wettability and density differences also results in poor recovery of graphite particles in aluminium melt. Good wetting is an essential condition for the generation of a satisfactory bond between particulate reinforcements and liquid metal during casting to allow transfer and distribution of load from the matrix to the reinforcements without failure. In the present work an attempt has been made to improve the wettability of reinforcement particles with aluminium by adding particles in two steps into the matrix.

Hard ceramic particulates such as zirconia, alumina, B_4C and SiC have been introduced into aluminium based matrix in order to increase the strength, stiffness, wear resistance, fatigue resistance. Among these reinforcements B_4C is compatible with aluminium and forms good bond with the matrix [8, 9].

Previous researchers revealed, at small amount of graphite contents poor lubrication and small matrix weakening occur. With increasing graphite content, the created graphite film completely separates the wear couple and at the same time protects the matrix, still resistant to plastic deformation. When graphite content exceeds a certain threshold level, weakening of the matrix is so much advanced that the lubricant film is no longer able to protect it effectively, so deformation and cracking are the prevailing phenomena. This graphite content plays an important role to determine the properties of composite.

In this study, an attempt has been made to prepare Al7475 alloy composites by adding 2, 4, 6, 8 and 10 wt. % of B_4C particulates with 37- and 88-micron size into matrix by using a novel two stage reinforcement addition method. Further, the prepared Al7475- B_4C composites were studied for mechanical properties and comparison has made between the 37 and 88 micron sized B_4C particulates reinforced composites.

Experimental Details

Table 1- Chemical Composition of Al7475 alloy by weight%

Zn	Mg	Si	Fe	Cu	Ni	Mn	Cr	Al
0.1	1.8	0.2	1.3	2.7	0.9	0.3	0.1	Balance

The aluminum alloys are basically classified into two categories these are cast aluminum and wrought aluminum. In the present research work Al7475 alloy is used as the matrix material which is one type of wrought aluminium alloy designated by 4 numbers, having zinc as the primary element and combined with various other elements like copper, magnesium, silicon and many more elements which are listed in chemical composition of Table 1. 660°C is the melting point of Al7475 alloy is and the density is 2.80 g/cc.

Boron Carbide is one of the hardest man-made materials available in commercial quantities. Boron carbide ceramics have excellent physical and mechanical properties, such as a high melting point, hardness, good abrasion resistance, high impact resistance and excellent resistance towards corrosion. As an outstanding in borne mechanical property, the boron carbide as a ceramic material have attracted attention over wide variety of applications that comprises light-weight armour plating, blasting nozzles, mechanical seal faces, grinding tools, cutting tools and neutron absorption materials.

37 micron ceramic B_4C particles were used as the reinforcement in the Al7475 alloy base matrix. Micro composites were produced by simplest and most economical used technique known as stir casting technique or vortex technique. Al7475 alloy is heated to the temperature of 750ºC in electrical resistance furnace. Thermocouple is used to check the temperature of the melt in the graphite crucible. At around 750ºC, powder of hexa-chloroethane (C_2Cl_6) [10] is added to the melt to remove all the unwanted trapped gasses and thus prevents casting defects like blow holes and porosity. Next, magnesium was added to decrease the surface tension and viscosity of the melt. The required quantities of preheated B_4C were taken in separate containers and added to Al7475 melt with continuous stirring for about 5-6 minutes at 300-350 rpm by zirconium-coated stirrer until a clear vortex is formed leading to good bonding, increase in the wettability between matrix and reinforced particles and to avoid agglomeration aimed at obtaining uniform homogenous distribution of reinforced particulates in the melt.

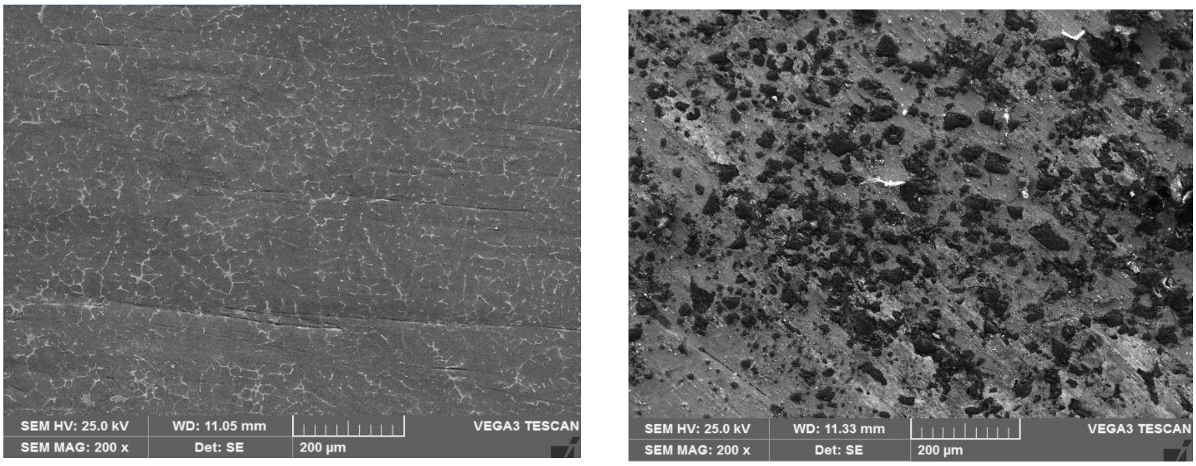
After mixing of the reinforcement particulates, the temperature of the melt reduced and started to solidify following which the melt was superheated above the liquid temperature with continued stirring and finally poured into permanent mould made of cast iron and allowed to solidify. After complete solidification, the casting is removed from the mould. Composites thus prepared were machined according to the ASTM standards. Now the Al7475-2, 4, 6, 8 and 10 wt.% of B_4C composite samples were subjected to various tests. Samples were tested for microstructural characterization by using Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscope (EDS). Tensile behaviour like ultimate tensile strength and yield strength were evaluated as per ASTM standards.

RESULTS AND DISCUSSION

Microstructural Study

The work accomplished here is an attempt made to develop Al7475 aluminium alloy composites reinforced with 37 and 88 micron sized boron carbide particulates by liquid metallurgy stir casting technique. The metallographic specimens are prepared through standard procedure of mechanical polishing further etching with a keller's chemical solution, which is commonly used for Al alloys and its composites. The particle distribution in the Al7475 alloy matrix at various fabrication conditions are examined through scanning electron microscope.

Fig. 1 (a) shows microstructure of as cast Al7475 aluminium alloy, fig. 1 (b) represents Al7475-10 wt.% B_4C composites with 37 micron sized particles. The SEM micrograph reveal almost uniform distribution of B_4C particulates throughout the matrix as observed in the fig. 1 (b) below. Uniformly distributed particulates increase the overall strength and other properties reducing the porosity of the MMC.



(a) (b)

Fig. 1: Scanning Electron Microphotographs of (a) as cast Al7475 alloy (b)Al7475-10 wt.% of 37-micron B_4C particles

Fig. 2 shows microstructure of Al7475-10 wt.% B_4C composites with 88 micron sized particles. The SEM micrographs reveal almost uniform distribution of B_4C particulates throughout the matrix as observed in the fig. 2 below. Uniformly distributed particulates increase the overall strength and other properties reducing the porosity of the MMC.

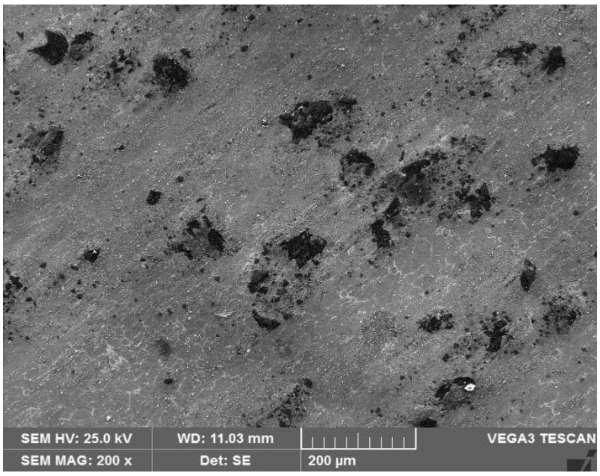
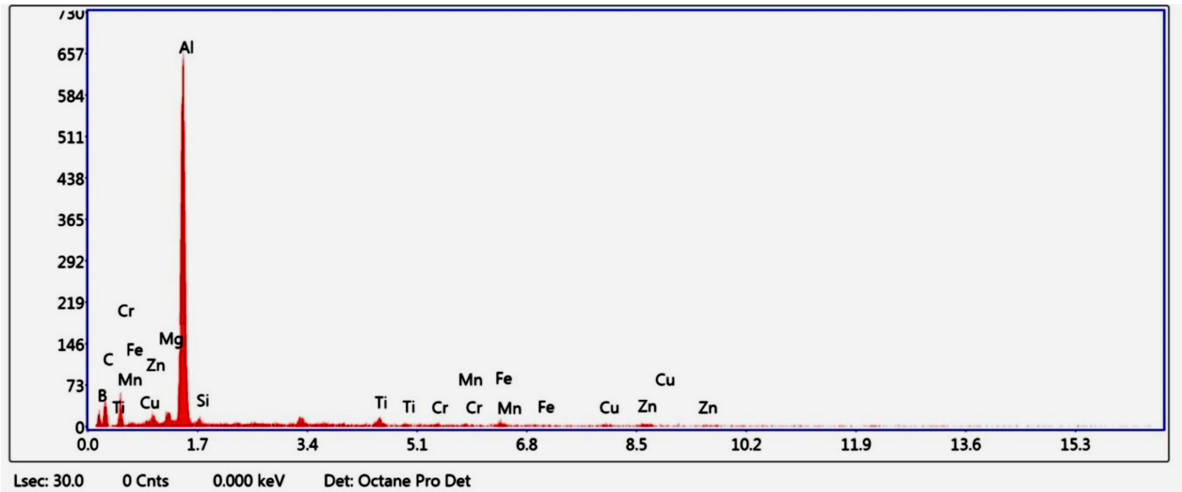
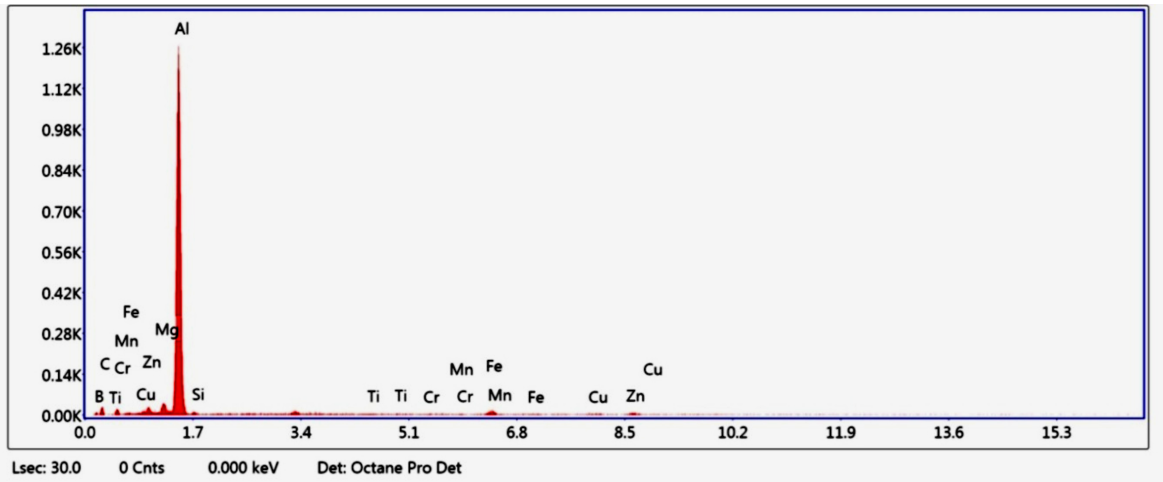


Fig. 2: Scanning Electron Microphotograph of Al7475-10 wt.% of 88-micron sized B_4C particles reinforced composites



(a)



(b)

Fig. 3: Energy Dispersive Spectrograph of (a) Al7475 - 10 wt. % 37 µm B_4C Composite (b) Al7475 - 10 wt. % 88 µm B_4C Composite

Fig.3 a-b showing the energy dispersive spectrographs of as cast Al7475 alloy -10 wt.% of 37 micron sized B_4C particulates reinforced composites and Al7475-10 wt.% of 88 micron size B_4C reinforced composites. In the composites B_4C particles presence was identified by the B and E elements.

Tensile Properties

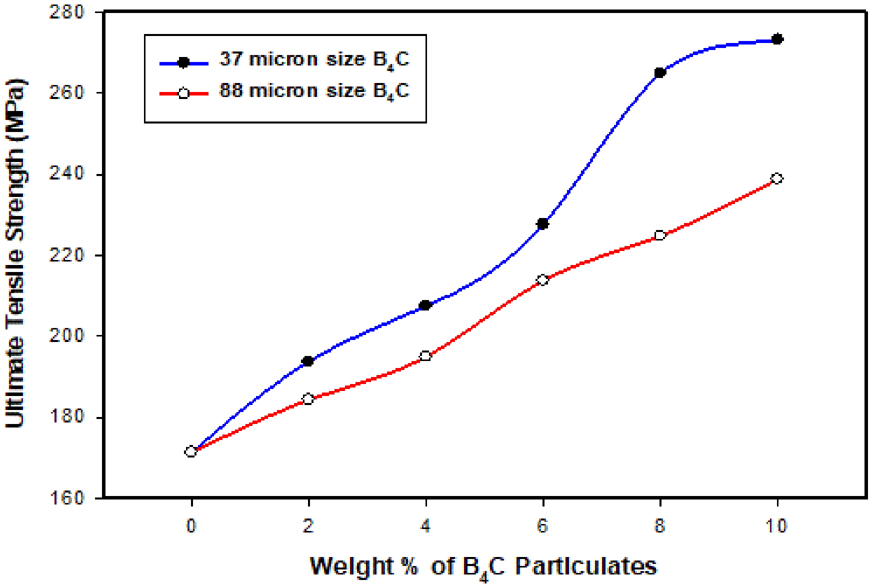


Fig. 4: Comparison of UTS of Al7475 alloy with 37- and 88-micron size B_4C reinforced composites

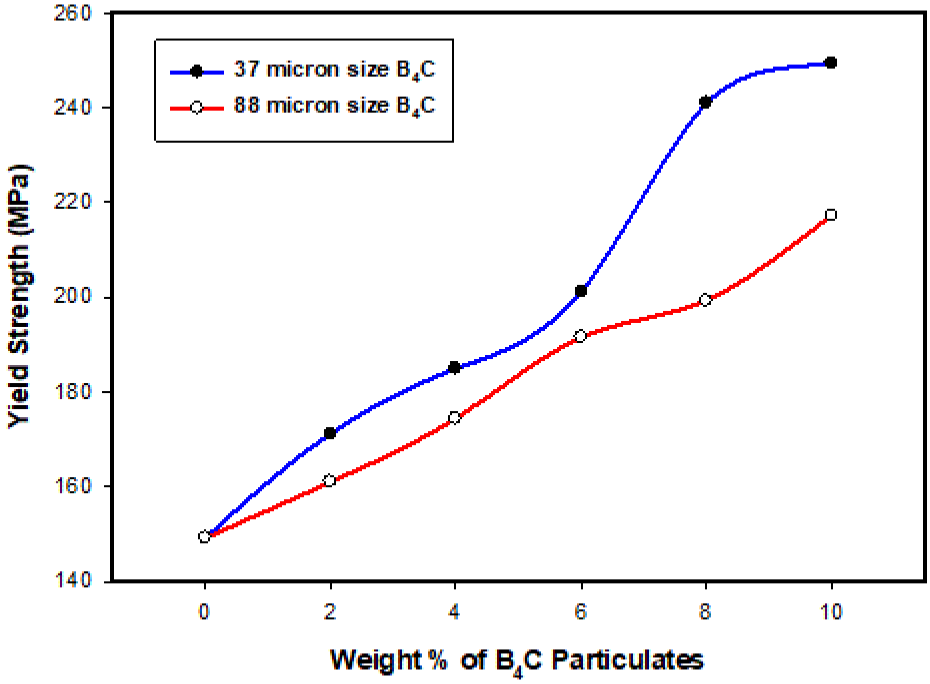


Fig. 5: Comparison of YS of Al7475 alloy with 37- and 88-micron size B_4C reinforced composites

Fig. 4 and 5 are demonstrating the comparison of ultimate tensile strength and yield strength of Al7475 alloy with 2, 4, 6, 8 and 10 weight percentages 37 and 88 micron sized B_4C particulates reinforced composites. From the graph it is evident that as the weight percentage of reinforcement particles increases from 2 wt. % to 10 wt. %, there is increase in UTS and YS of Al7475 alloy in the both 37 and 88 micron sized composites.

Further, 37 micron sized B_4C composites are exhibited more ultimate and yield strength values as compared to the 88 micron sized B_4C composites. The UTS of base matrix Al7475 alloy is 171.3 MPa after adding 2, 4, 6, 8 and 10 weight percentages of 37 mµ sized B_4C particulates, the ultimate strength values are 193.6, 207.4, 227.57, 264.8 and 273.1 MPa respectively. Similarly, in the case of 2, 4, 6, 8 and 10 weight percentages of 88 mµ sized B_4C particulates reinforced Al7475 alloy composites, it is 184.2, 194.8, 213.7, 224.7 and 238.7 MPa respectively.

The yield strength of base matrix Al7475 alloy is 149.1 MPa after adding 2, 4, 6, 8 and 10 weight percentages of 37 mµ sized B_4C particulates, the yield strength values are 171.1, 184.9, 201.1, 240.9 and 249.3 MPa respectively. Similarly, in the case of 2, 4, 6, 8 and 10 weight percentages of 88 mµ sized B_4C particulates reinforced Al7475 alloy composites, it is 161, 174.3, 191.5, 199.2 and 217.1 MPa respectively.

From the values it is noticed that the ultimate and yield strength of 37 mµ sized B_4C composites are superior than the 88 mµ B_4C composites. The enhancement of UTS and YS is more in smaller particles reinforced composites, this increase is due to good wettability of particles in the Al7475 alloy matrix. This is noticeable by microstructural studies also. As particles size decreases the reinforcement bonding increases with the matrix alloy [11, 12].

Fig. 6 is demonstrating the comparison of percentage elongation of Al7475 alloy with 2, 4, 6, 8 and 10 weight percentages 37 and 88 micron sized B_4C particulates reinforced composites. From the graph it is evident that as the weight percentage of reinforcement particles increases from 2, 4, 6, 8 and 10 wt.%, there is decrease in % elongation of Al7475 alloy in the both 37 and 88 micron sized composites. This decrease in percentage elongation is due to presence of hard ceramic particles in the soft Al matrix Al7475 alloy. As the weight % of hard particles increases in the matrix material, these hard B_4C particles converts the soft matrix into brittle, which in turn results the decrease in ductility of Al7475-B_4C composites [13, 14]. Further, the ductility of Al7475 alloy with 37 micron sized B_4C particles and 88 micron sized B_4C particles reinforced composites are almost same in nature.

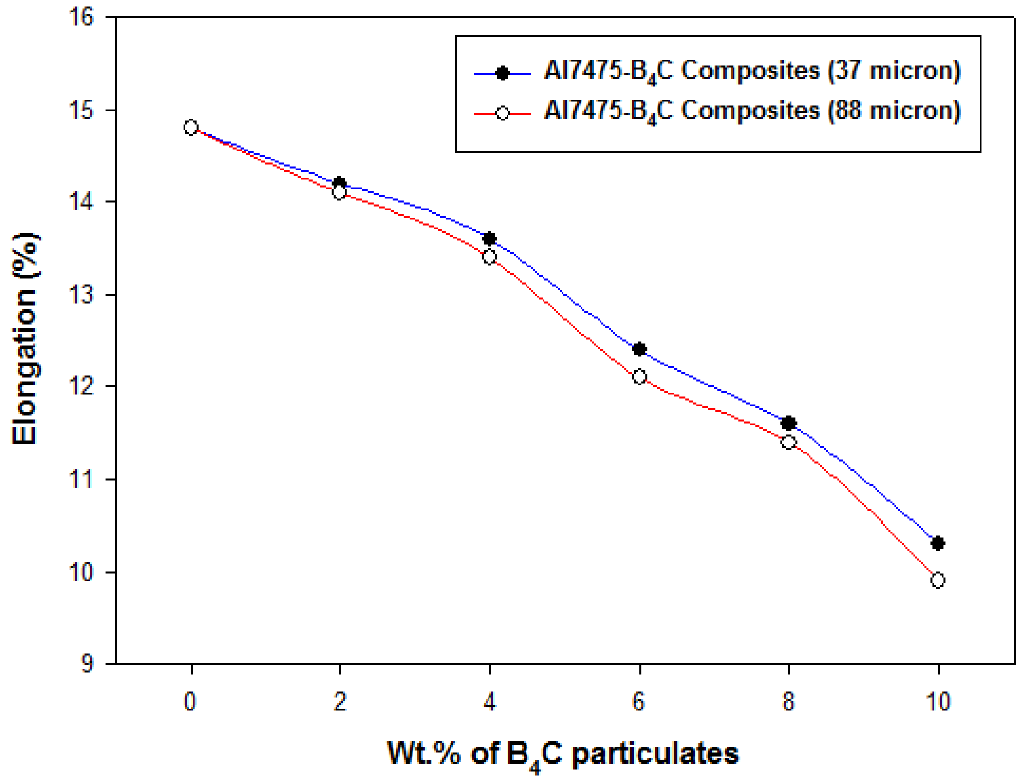


Fig. 6 : Comparison of elongation of Al7475 alloy with 37 and 88 micron size B_4C reinforced composites

CONCLUSIONS

Based on the research work, the overall conclusions made on the work entitled, “Tensile properties of varying size B_4C particulates reinforced Al7475alloy composites” has led to the following conclusions:

1. Al7475 alloy with 2, 4, 6, 8 and 10 wt. % of 37 micron sized B_4C particulates reinforced composites have successfully fabricated by stir casting route.
2. Al7475 alloy with 2, 4, 6, 8 and 10 wt. % 88 micron sized B_4C particulates reinforced composites have successfully fabricated by stir casting route.
3. The SEM analysis revealed the distribution of 37 and 88 micron sized B_4C particles in Al7475- B_4C composites.
4. The energy dispersive (EDS) analysis revealed the presence of 37 and 88 micron sized B_4C particles in Al7475- B_4C composites in the form of B and C elements.
5. Improvements in ultimate tensile strength and yield strength of the Al7475 matrix are obtained with the addition of B_4C particulates.
6. The ultimate tensile strength of Al7475 alloy improved from 171.1 MPa to 273.1 MPa and 238.7 MPa respectively in 10 wt. % of 37 and 88 micron sized B_4C particulates reinforced composites.
7. Percentage elongation of Al7475 alloy decreased with the addition of 37 and 88 micron sized B_4C particles. It is decreased further as weight percentage of reinforcement increases from 2 to 10 wt. %. This decrease in & elongation is almost same in both 37 and 88 micron sized B_4C composites.

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