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Microstructural characterization, mechanical and wear behaviour of Al2024-B_4C composites for aerospace applications

Metal matrix composite plays an important role in automobile and aerospace applications. Among all the metals, aluminium is considered as the lighter metal. In present investigation aluminium-2024 is considered as the base alloy and reinforced with boron carbide to increase its hardness. Aluminium metal matrix composite is obtained by combining different percentage of boron carbide particulates in the volume fraction 2.5 wt.% and 5 wt.%. Synthesis is done by stir casting technique and the characterization is carried out using scanning electron microscope. The properties of Al2024 reinforced with boron carbide is evaluated by using tensometer, pin on disc wear testing machine and vickers hardness tester. With the increase in the reinforcement high hardness, tensile strength and higher wear resistance is achieved. These types of MMCs are widely used in automobile and aerospace applications due to their great mechanical behaviours, low density, low factor of thermal expansion; corrosion resistance is better and increased wear resistance as compared to conventional metals and alloys. Improved mechanical property of these composites makes them very useful for various applications in many areas from technological point of view.

Keywords: Microstructure, mechanical and wear behaviour, composite technology, AL2024–B_4C

1.0 Introduction

Different types of composite materials are available and these are increasing with time as a result of new advancements and good enhanced properties [1, 2]. Performance oriented demands on materials has naturally resulted in revival of the age-old concept of combination of various materials for optimum performance unattainable by individual constituent to meet specified user requirement with an added advantage of a flexible tailor-made material as per specifications required for optimum use. Today technological development very largely depends on the advance in the field of material. To this end, a very large leap in optimum use of constantly endeavouring materials is composite [3].

Composite technology, an interdisciplinary approach, encompasses fields like physics, engineering, chemistry, polymer science, material science, engineering, etc [4, 5]. Composite contains a phase called matrix that holds together and gives form to stronger, stiffer reinforcement constituent resulting in a material with perfect blend of structural properties far better than its constituent parts alone [6]. Combination of properties that make composites superior over conventional structural materials are good design flexibility, high specific strength and specific modulus, high fatigue endurance limit, corrosion and wear resistance, thermal cycling tolerance, tolerable coefficient of thermal expansion etc [7]. Relative amount and properties of constituent phases, geometry of dispersed phase including particle size, shape, and orientation in the matrix directs properties of composites. There are several fabrication techniques available to process composites. The prepared composites are usually evaluated for enhanced properties by conducting experiments like hardness, tensile, compression, fatigue, and tribological tests as per ASTM standards [8].

AMMCs can be fabricated in many tested methods, but no one unique procedure. The fabrication technique depends on matrix material and types of reinforcement used. Of all manufacturing processes that are available for short fiber metal matrix composite, stir casting is commonly acknowledged promising route on account of its simplicity, flexibility, large scale production of applications.

In the present study, Al2024 alloy with 2.5 and 5 weight percentages of B_4C reinforced composites were synthesized by stir cast method. Thus prepared composites were

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evaluated for tensile, wear and hardness properties as per ASTM methods.

2.0 Materials and methods

2.1. Materials

In the present work, aluminium 2024 as the base matrix and B_4C as the reinforcing particulates is selected and the chemical composition of the matrix alloy is given in the Table 1.

2.2. Composite Fabrication

The aluminium 2024 alloy containing 2.5 and 5% wt. of boron carbide particulates reinforced composite were fabricated by stir casting method to ensure uniform distribution of the reinforcements. The aluminium alloy, initially in the form of a block which will be cut into small pieces then it is placed into the graphite crucible. Aluminium alloy was heated up to 750^{o}C with the help of the electric furnace. Meantime the reinforcement i.e., B_4C along with the die is preheated around 300^{o}C. After the melting of aluminium alloy in the crucible then the degassing tablet known as hexachloroethane (C_2Cl_6) [9] is added into the crucible in order to remove any absorbed gases and the slag from the molten metal. Along with the preheated reinforcement, Potassium titanium nitride (K_2TiF_6) is added into it basically, it improves the wettability between the reinforcement and the matrix. With the help of the zirconium coated mechanical stirrer the mixing of the molten metal takes place at a constant speed of 300 rpm. After continuous stirring, the entire molten metal is poured into the preheated die to get a required specimen. The same procedure is followed to get the MMC's having different wt. % (0,2.5,5 %) of B_4C particulates.

2.3 Testing

The Microstructural behaviour was checked through SEM and the fabricated specimens were proposed to test for mechanical properties like tensile strength, wear and hardness as per ASTM standards [10]. Fig.1 (a-b) are showing the tensile test specimen dimensions and prepared specimen for the study.

3.0 Results and discussion

3.1 Microstructural Behaviour

In present investigation on Al-2024 composed with B_4C particle for various range of wt.% of its behaviour and to evaluate its true property to identify its microstructural behaviour. A scanning electron microscope (SEM) is used to magnify the views and also to reveal the uniform distribution of B_4C particulates, there are various range of microscope is being available but purpose of using SEM is because of their

Table 1: Composition of matrix material

Elements	Cu	Mg	Si	Fe	Mn	Zn	Ti	Cr
% by wt.	4.4	1.40	0.09	0.2	0.6	0.02	0.04	0.02

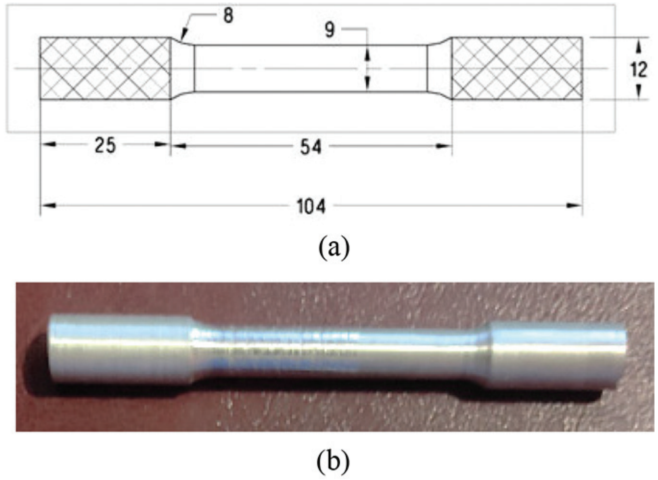


Fig.1: Tensile test (a) specimen dimensions (b) specimen prepared for study

ease in operational condition, accuracy in results and also wide use of SEM for research application. Fig.2 (a-c) shows involvement of particulates which is kept on increasing with increase in % of reinforcement for 0, 2.5 and 5% wt., reinforcement are allowed to undergo test to reveal the microstructure of the composite.

Fig.2 (a) is demonstrating the SEM image of as cast Al2024 alloy. This microphotograph indicates the suitability of casting process adopted to prepare the Al based composites. The surface of the as cast alloy is free from pores and other casting defects. Further, Fig.2 (b-c) is showing presence of born carbide particles in the Al2024 alloy.

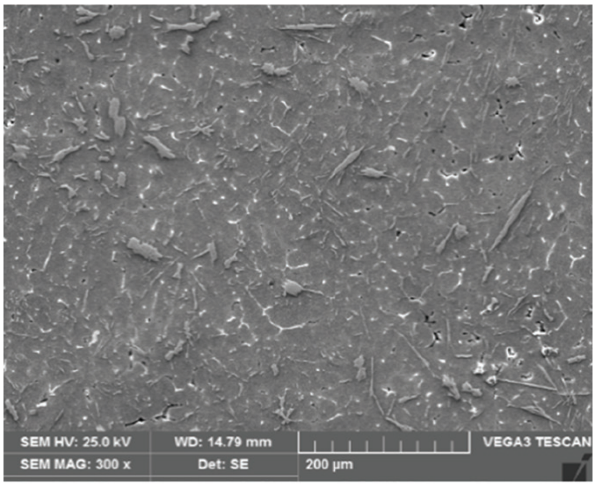
3.2 Tensile Properties

The tensile test is conducted to identify elastic behaviour of the material composite. It is known that material tends to give results in test differently at different temperature conditions hence adopting room temp as the actual working temperature while conducting experiment.

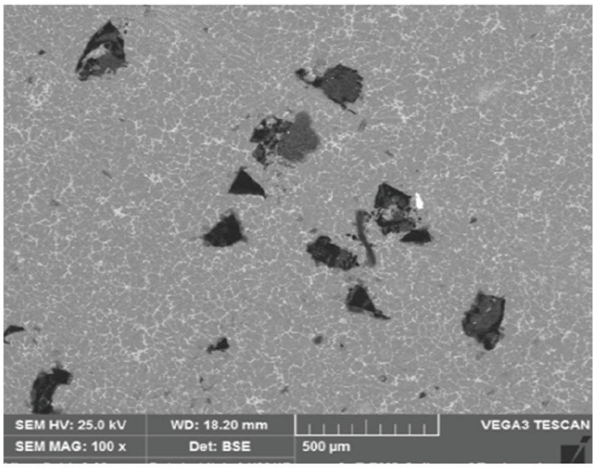
The results showed that as the wt. % of B_4C content increases the elongation of the specimen decreases.

Fig.3 is the graph of which shows the result of ultimate tensile strength (UTS) and yield strength (YS), results which are being obtained in test are tabulated on each type of reinforcement. From the graph it is known that as the % of reinforcement increases ultimate as well as yield strength too increases.

The B_4C particles in matrix alloy provide protection to softer material matrix. The addition of hard ceramic particle improves mechanical properties mainly by stress transference from Al 2024 alloy matrix to B_4C particles. This is because of dislocation mechanism by which a dislocation by pass impenetrable obstacles where a dislocation bows out considerably to leave a dislocation part [11]. From the result, it can be seen that the elongation of composites decreases as the increase of B_4C content in the Al 2024 alloy matrix.



(a)



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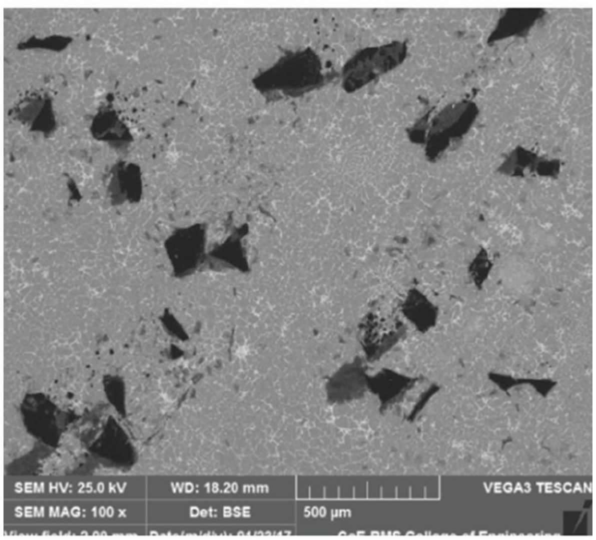

(c)

Fig.2 Scanning electron microphotographs of (a) as cast Al2024 alloy (b) Al2024-2.5 wt.% of B_4C (c) Al2024-5 wt.% of B_4C composites

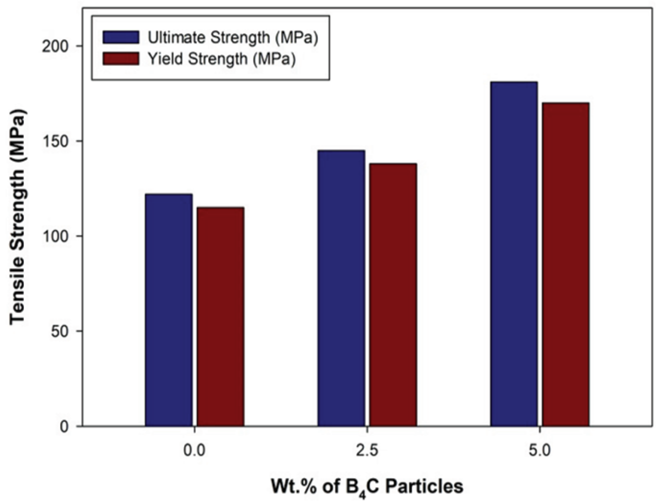

Fig.3: Ultimate and yield strength of Al2024 alloy and its B_4C reinforced composites

TABLE 2: TENSILE TEST RESULTS

	Wt.% of B_4C	Ultimate Strength (MPa)	Yield Strength (MPa)	Elongation (%)
1.	0	122	115	2.1
2.	2.5	145	138	1.8
3.	5	181	170	1.2

Thus, particles aggregated at grain boundaries intensified the stress concentration. So, the addition of B_4C particles reduced the elongation of the matrix. As the ceramic particle contents increased in the soft Al 2024 alloy matrix.

Fig.4 is indicating the percentage elongation of Al2024 alloy with 2.5 and 5 weight percentage of boron carbide reinforced composites. Percentage elongation of as cast Al2024 alloy is 2.1%, further with the addition of 2.5 wt.% of boron carbide particles is 1.8% and 1.2% with the 5 wt.% of boron carbide particles.

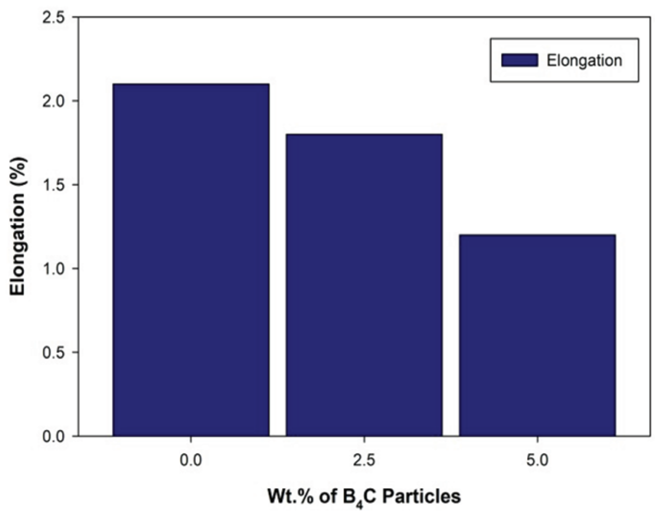

Fig.4: Percentage elongation of Al2024 alloy and its B_4C reinforced composites

TABLE 3: WEAR TEST RESULTS

	Wt.% of B4C	Wear rate in microns
1.	0	23
2.	2.5	17
3.	5	13

3.3 Wear Behaviour

The wear tests are conducted on the Al 2024 alloy and its B_4C reinforced composites at varying loads of 20, 30 and 40N at 400 rpm constant sliding speed and for a sliding distance of 2000m. Similarly, experiments are conducted at varying proportions of B_4C reinforcement at constant sliding distance of 2000m. For all the tests the wear is noted in terms of height loss in micro-meter (μm).

The load is one of the important parameters which plays a significant role in wear loss. A lot of work has been carried out on the effect of normal load in wear experiments to understand the wear rate of aluminium alloys. Further, to study the effect of load on wear, graphs have been plotted for wear loss against different loads of 20, 30 and 40N at constant distance of 2000m and speed of 400 rpm. Table 3 shows the effect of load on the wear behaviour of AA2024 alloy and 0%, 2.5% and 5 wt.% of B_4C reinforced composites.

From the Fig.5 it is noticed that by increasing the load the weight loss also increases, but by the increasing content of the boron carbide wear loss is decreased. The decrease is wear loss by increasing the weight % of boron carbide particles is mainly due to high hardness of carbide particles which acts as resistance to wear of the surface [12]. Further, as applied loss increased from the 20 N to the 40 N, there is an increase in the wear loss, which is due to more surface area of the specimen in contact at higher applied loads.

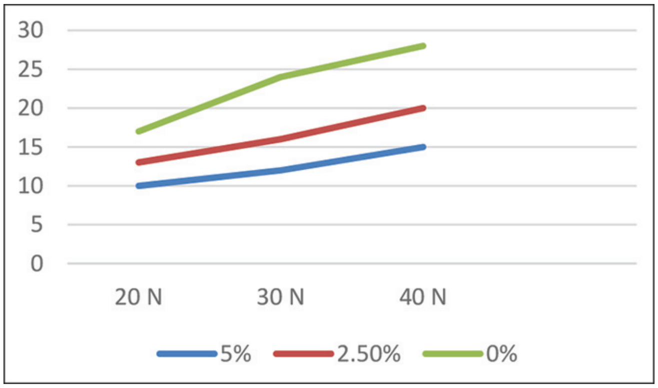

Fig.5: Graph of wear Vs load for the specimen at different wt. % of reinforcement

TABLE 4: HARDNESS TEST RESULTS

	Wt.% of B_4C	Hardness (VHN)
1.	0	110
2.	2.5	160
3.	5	180

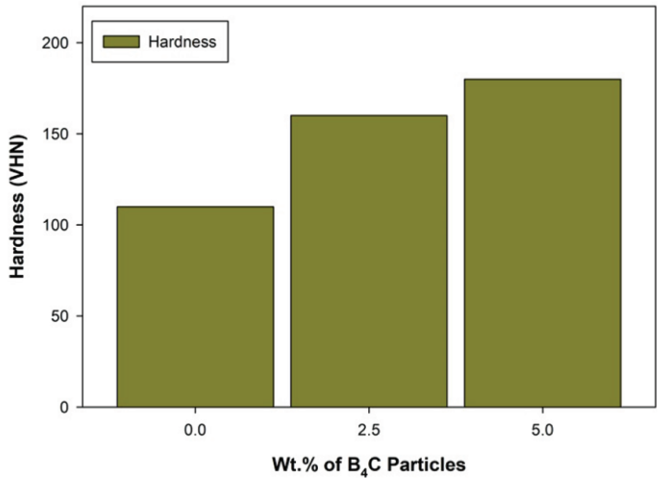

Fig.6 Hardness of Al2024 alloy and its B_4C reinforced composites

3.4 Hardness Measurements

Table 4 and Fig. 6 demonstrates the variety in hardness with the expansion of 2.5 and 5 wt.% of B_4C particulates in the Al2024 alloy. The hardness of a material is a mechanical parameter demonstrating the capacity of opposing nearby plastic twisting. The hardness of Al 2024-B_4C composite is found to increment with the addition of wt.% B_4C particulates. This expansion is seen from 110 VHN to 180 VHN for Al 2024-B_4C composites. In the present work also after the addition of B_4C particles higher hardness is observed in the case of composites.

It is observed that, the hardness of AMCs has increased with increase in wt.% of reinforcement. Addition of reinforcement particles in the melt provides additional substrate for the solidification to trigger thereby increasing the nucleation rate and decreasing the grain size. The Vickers hardness test of AMC's is found to be 110 VHN for as cast and for wt.% of 2.5% it is found to be maximum 160. For wt.% of 5% it is found to be maximum 180. The presence of such hard surface area of particles offers more resistance to plastic deformation which leads to increase in the hardness of composites [13, 14]. Fig.6 shows the graph of reinforcement vs harness number.

4.0 Conclusions

The Al2024 metal matrix composites were produced with different percentage of B_4C particles (2.5% and 5%) reinforcement and then the microstructure test, tensile test, hardness test and wear test were conducted and the following conclusions are derived

- From the microstructure it can be seen that the B_4C particles are present and they are uniformly distributed across the matrix material.
- During the tensile test it was found that as the reinforcement % increases the yield and ultimate strength of material also increases. The main reason for this is

better bonding and uniform dispersion of boron particles.

- From the hardness test of AMC, it was found to be maximum for 5% of B_4C reinforced composites.
- From the wear test results it was found that as reinforcement wt.% increases the rate of wear decreases. Further, as applied load increased from 20 N to 40 N there was increase in wear loss of as cast alloy and its boron carbide particles composites.

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