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Mechanical characterization and wear behavior of aerospace alloy AA2124 and micro B_4C reinforced metal composites

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Abstract

In the present investigation, the mechanical and wear properties of aerospace alloy AA2124-9 wt% of B_4C composites were displayed. The composites containing 9 wt% of micro boron carbide in AA2124 alloy were synthesized by liquid metallurgy method through stir casting. For the composites, reinforcement particles were preheated to a temperature of 400°C and afterward added in ventures of two stages into the vortex of liquid AA2124 alloy compound to improve the wettability and dispersion. Microstructural examination was carried out by SEM and elemental investigation was finished by EDS. Mechanical and wear properties of as cast AA2124 alloy and AA214-9 wt% of B_4C composites were evaluated as per ASTM standards. Microstructural characterization by SEM and EDS confirmed the distribution and presence of micro boron carbide particles in the AA2124 alloy matrix. The hardness, ultimate strength, yield strength and bending behaviour of AA2124 alloy enhanced with the incorporation of 9 wt% of micro B_4C particles. The hardness of as-cast AA2124 alloy was 65.76 BHN; it is 96.7 BHN in 9 wt% of B_4C reinforced composites. The ultimate and yield strength of AA2124 alloy was 187.08 MPa and 150.33 MPa respectively. The enhanced UTS and YS in 9 wt% of B_4C reinforced composites were 254.1 MPa and 203.7 MPa, respectively. Further, ductility of AA2124 alloy decreased with the presence of B_4C particles. Wear resistance of aerospace alloy increased with the addition of micro particles. Tensile fractography and worn surface morphology were studied on the tested samples to know the various fractured and wear mechanisms.

1. Introduction

Composite materials are that type of structural material which is the mixture of two or more constituents which may or may not be similar to each other. These constituents are combined at macroscopic level and are insoluble in each other in the composite material, one of the constituents acts as a matrix and other one act as reinforcement. The material acts as a matrix material provide the base for the material which acts as the reinforcement material [1-3].

The addition of reinforcement material into the matrix material results in the enhancement of the mechanical properties when compared to the base material. The properties like hardness, strength and bending stress are enhanced properties of the metal matrix composites while comparing it from the base metal properties [4,28]. The reinforced material used in the matrix can be classified as a fiber, particulate or flake, and whiskers [5].

Metal matrix has enhanced mechanical properties than the pure metal. Composite materials are widely used as a commercial material in the cutting tools industry due to its high strength, stiffness, wear resistance, thermal conductivity, and low density. There are several techniques available for the fabrication of these cast composite but the liquid metallurgical technique known as vortex method is one of the best methods to fabricate the cast due to less residual void, no dissolved gases in a final product, a good interface between the reinforcement and the matrix material [6,29].

The easy availability of raw materials, good mechanical and wear properties make Al-based metal matrix more comfortable in the research work [7,8]. There are numerous benefits of MMC's. From the industrial point of view which improves various mechanical properties such as wear life, fatigue life, corrosion behaviour, benefits for an environment like noise resistance and easy machineability makes the reduction in the economic cost. The reinforcement particulate such as graphite, silicon carbide, TiC, ZrO_2, B_4C etc. is added to improve the wear resistance, corrosion resistance and mainly hardness of the base metal [9,30]. Number of metal matrix composites are available, copper, zinc, tin, titanium, magnesium, aluminium and its alloy are also among them which is widely used in automobile and aerospace industry due to its easy availability, good corrosion resistance, and high thermal conductivity.

Boron synthetically combined with carbon results in a very hard ceramic known as boron carbide, B_4C being the third hardest material after cubic boron nitride (CBN) and diamond, it is used as abrasion material to combat wear [31]. Because of its high hardness and low density the material can be used in aluminium matrix alloy in the form of particulates to produce composition material.

Especially for the aerospace applications it is necessary to have the advanced materials in order to reduce the overall weight of an aircraft.

Further, the materials should capable to withstand at high loads and temperature conditions. By considering these parameters, in the present work B_4C particles of 90 micron in size were selected as a reinforcement, which are having 2.52 g·cm^{-3} density. Aluminium 2 series alloys are most suitable alloys for aerospace applications, hence AA2124 alloy is used in the present study to synthesize AA2124-9 wt% of B_4C composites. AA2124-9 wt% B_4C composites were prepared by using two step stir casting technique to enhance the wettability. Further, mechanical and wear behaviour of as cast alloy and its composites were evaluated as per standard testing methods.

2. Experimental

2.1 Materials

In the present study AA2124 alloy is used as the matrix material, most of the applications in areas such as aerospace, automobile, marine make use of 2xxx series, aluminium-copper alloys. AA2124 normally has 4.9% of copper and 1.8% of magnesium. The theoretical density of AA2124 alloy is taken as 2.80 g·cm^{-3}. Table 1 is representing the chemical composition of AA2124 alloy and Figure 1 is indicating the scanning electron micrograph of B_4C particles used in the study.

In the present work, micro B_4C particulates are used as the reinforcement materials, 80-90 micron size particulates were used, which were procured from Speed Fam Ltd., Chennai. The density of boron carbide is lesser than the matrix material, which is 2.52 g·cm^{-3}.

2.2 Preparation of composite and testing

The manufacture of AA2124-B_4C composites were completed by liquid metallurgy through stir cast method. Determined measure of the AA2124 compound ingots were kept into the heater for liquefying. The melting temperature of aluminum alloy is 660°C. The AA2124 alloy melt was superheated to 750°C. The temperature of the melt was recorded utilizing a chrome-alumel thermocouple. The liquid metal is then degassed utilizing solid hexachloroethane (C_2Cl_6) for 3 min [9]. A hardened steel impeller covered with zirconium is utilized to mix the liquid metal to make a vortex. The stirrer will be turned at a speed of 300 rpm and the profundity of drenching of the impeller was 60 percent of the height of the liquid metal from the outside of the liquefy. Further, the B_4C particulates were preheated in a heater up to 400°C will be brought into the vortex. Stirring was proceeded until interface connections between the fortification particulates and the Al matrix advances wetting. At that point, AA2124-9 wt% micro B_4C melt was poured into the cast iron mold having measurements of 120 mm length and 15 mm width.

The castings in this way got were sliced to a size of 15 mm diameter across and 5 mm thickness which is then exposed to various dimensions of cleaning to get required example piece for microstructure studies. At first, the cut examples were cleaned with emery paper up to 1000 grit size pursued by cleaning with Al_2O_3 suspension on a cleaning disc utilizing velvet material. The cleaned surface of the examples etched with Keller's reagent lastly exposed to microstructure in an electron microscope.

Table 1. Chemical composition of AA2124 Alloy.

Elements	Si	Fe	Cu	Mg	Cr	Zn	Ti	Mn	Al
Weight (%)	0.20	0.30	4.9	1.8	0.10	0.25	0.15	0.9	Bal

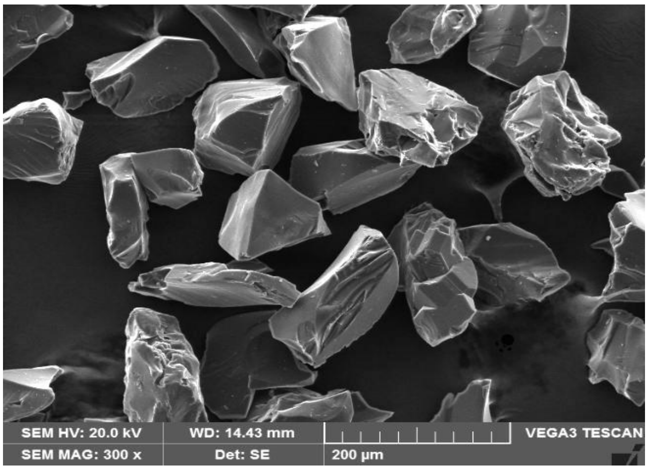

Figure 1. SEM microphotograph of B_4C particles used for the study.

Hardness tests were performed on the cleaned surface of the examples utilizing Brinell hardness testing machine having a indenter of 5 mm diameter and 250 kg load for a stay time of 30 s, five arrangement of readings were taken at better places of the cleaned surface of the example and test was performed according to ASTM E10 [10]. The tensile and bending tests were done on the cut examples according to ASTM E8 and E9 [11] standards utilizing universal testing machine at room temperature to ponder properties like UTS, yield strength, percent of elongation and bending strength. The tensile test specimen length is 104 mm with 12 mm holding diameter and 45 mm gauge length with 9 mm in diameter. The bending test has conducted using three point bending method as per ASTM E290.

The wear behaviour was studied by conducting wear test by using pin on disc machine (DUCOM, TR-20LE). The dry sliding wear tests were performed on both AA2124 alloy and AA2124-9 wt% B_4C reinforced composites by having a diameter of 8 mm and height of 30 mm as per ASTM G99 standards. The counter disc of wear machine was of EN32 steel material. Before the start of the testing process, the acetone liquid is used for cleaning of the disc and test pin surface. The various investigations were led at 3000 m sliding distance and 400 rpm steady sliding velocity through varying loads of 20, 30 and 40 N. Similarly, tests were conducted at 40 N constant load through varying speeds of 100, 200, 300 and 400 rpm. Among testing, the test pin was kept opposite and stationary to the spherical steel disc while the circular plate was pivoted. For all the tests the wear is noted in terms of height loss in micro-meter (μm). Figure 2 and Figure 3 show the test specimens for tensile and wear properties respectively.

Figure 2. Tensile test specimen.

Figure 3. Stir casting set up.

3. Results and discussion

3.1 Microstructural study

Figure 4(a-b) shows the SEM micrographs of as cast alloy AA2124 alloy and the composites of 9 wt% of micro B_4C reinforced with AA2124 alloy. These two examined samples were chosen from the middle segment from the cylindrical specimens. The microstructure of as cast AA2124 alloy comprises of fine grains of aluminium solid solution with an enough dispersion of inter-metallic precipitates.

Figure 4(a) shows the scanning electron photograph of 9 wt% of B_4C particulates reinforced composites. From the SEM photograph, it is revealed that there is uniform homogenous distribution of secondary phase of micro particulates in the AA2124 alloy matrix without any agglomeration. It is also observed that there is an excellent interfacial bonding between the B_4C and AA2124 alloy matrix, which further enhances the properties of AA2124 alloy.

From the Figure 5 it is evident that micro B_4C particles are presented in the AA2124 alloy matrix in the form of B and C elements along with Al and Cu.

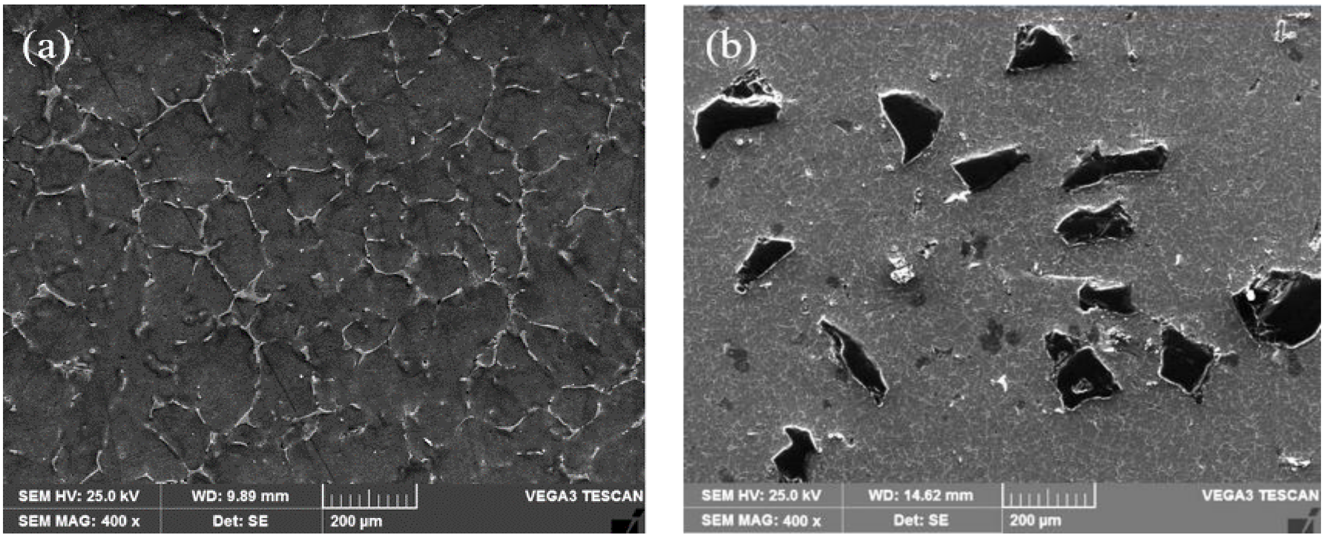

Figure 4. SEM microphotograph of (a) as cast AA2124 alloy and (b) AA2124-9 wt% B_4C composites.

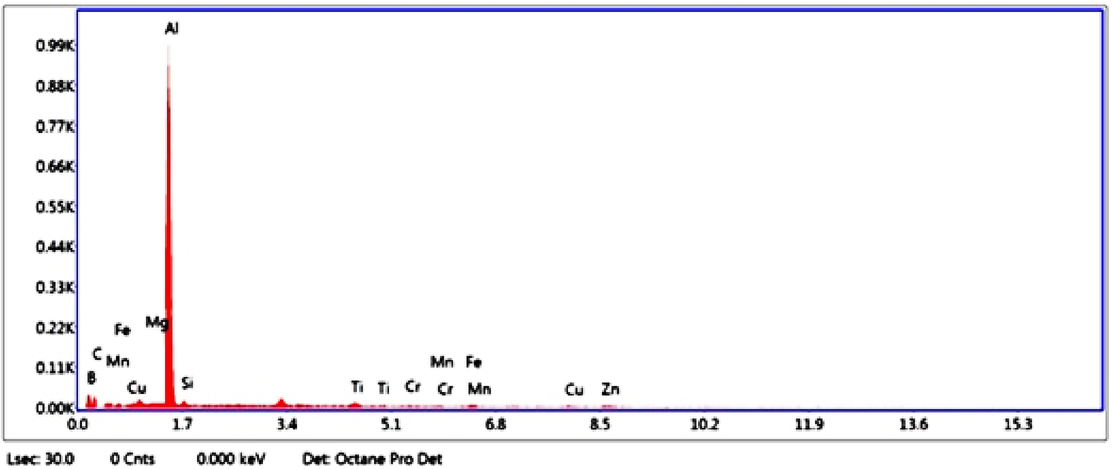

Figure 5. Showing the energy dispersive spectrograph of AA2124-9 wt% B_4C composites.

Figure 6 shows the X-ray diffraction (XRD) pattern taken for AA2124- 9 wt% B_4C composites to verify its quality and standard XRD pattern. It can be observed that peak height increases and then decreases on 2-theta scale indicating the presence of different phases of material. The JCPDS number for the Al-B4C composites is 33-0225. In Figure 6, it is visible that X-ray intensities of peak are higher at 38˚, 45˚, 65˚ & 78˚ indicating the presence of aluminium phase. Similarly, in Figure 6 it is observed the peaks for different phases of boron carbide at 32˚, 37˚, 50˚ and 53˚.

3.2 Density measurements

Figure 7 compares the theoretical and experimental densities of as cast AA2124 alloy, and AA2124-9 wt% B_4C composites. Aluminium alloy AA2124 has density of 2.8 $g \cdot cm^{-3}$, boron carbide has density of 2.52 $g \cdot cm^{-3}$. When aluminium alloy AA2124 is reinforced with 9 wt% B_4C, the overall density of composite becomes less as B_4C density is lesser than AA2124 alloy. Further, it can be observed that experimental densities are lesser than the theoretical densities and also the experimental density of as cast Al2124 alloy and 9 wt% of micro B_4C composites are almost nearer to the theoretical density values, which indicates the suitability of fabrication method adopted.

3.3 Hardness measurements

Figure 8 demonstrates the variety in hardness with the expansion of 9 wt% of micro B_4C particulates to the AA2124 alloy. The hardness of a material is a mechanical parameter demonstrating the capacity of opposing nearby plastic twisting. The hardness of AA2124-B_4C composite is found to increment with the addition of 9 wt% micro B_4C particulates. This expansion is seen from 65.76 BHN to 96.7 BHN for AA2124-B_4C composites. This can be attributed essentially to the closeness of harder carbide particles in the cross section, and moreover the higher limitation to the restricted framework disfigurement amid space because of the nearness of harder stage [12]. Furthermore, B_4C, as like different fortresses strengthens the framework by creation of high-density disengagements in the midst of cooling to room temperature due to the qualification of coefficients of thermal extension improvements between the B_4C and network AA2124 compound. Confound strains created between the support and the lattice deters the development of separations, bringing about progress of the hardness of the composites [13]. Mazahery *et al.* [25] investigated the hardness behavior of A356 alloy with the nano SiC particles; it was found that hardness of A356-nano SiC composites is higher than that of the non-reinforced A356 alloy. In the present work also after the addition of nano B_4C particles higher hardness is observed in the case of composites.

3.4 Ultimate tensile strength and yield strength

The plot of ultimate strength (UTS) and yield strength with 9 wt% of B_4C dispersoid in metal grid composite has been presented in Figure 9. The conscious estimations of UTS were plotted as a segment of weight rate of boron carbide particles. The ultimate and yield strength of AA2124 alloy is enhanced with the addition of 9 wt% of B_4C particles. The extent of improvement obtained in the UTS after the addition

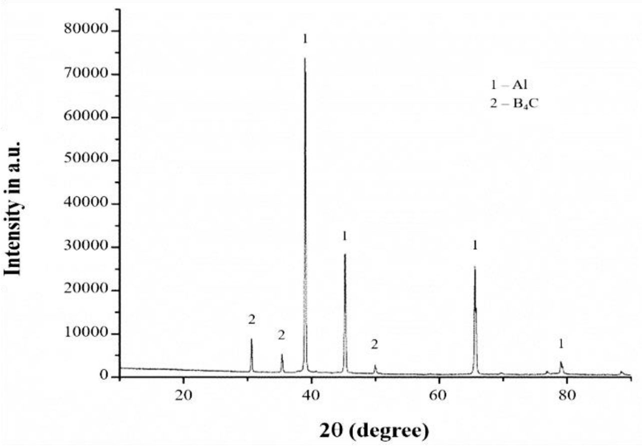

Figure 6. XRD pattern of AA2124-9 wt% of B_4C composite.

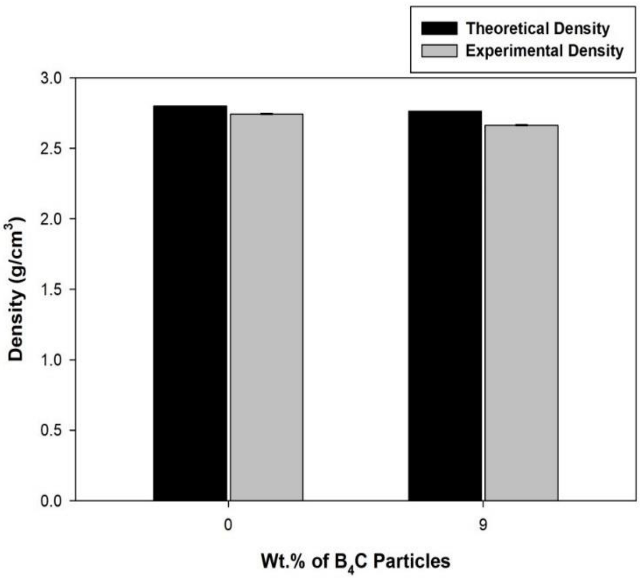

Figure 7. Densities of AA2124-9 wt% of micro B_4C composites.

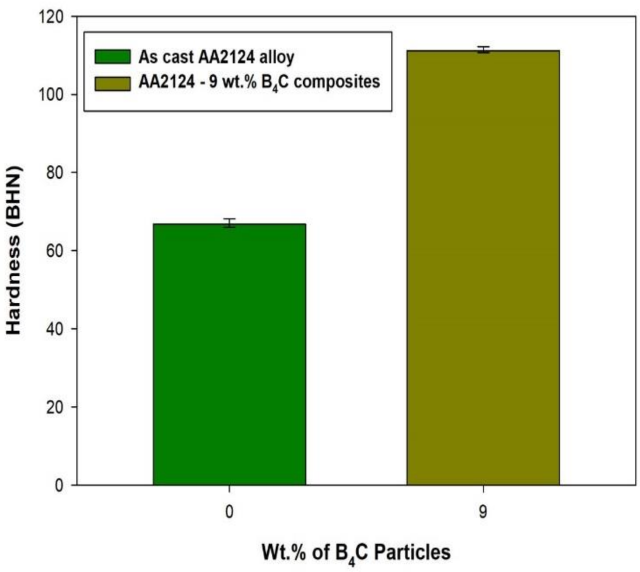

Figure 8. Showing the error graph for hardness of AA2124 alloy-9 wt% of B_4C composites.

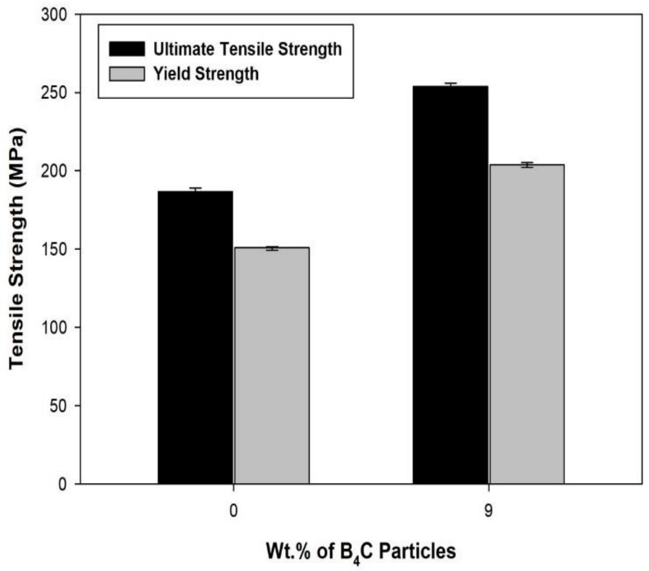

Figure 9. Showing the error graph for ultimate tensile and yield strength of AA2124 alloy-9 wt% B_4C composites.

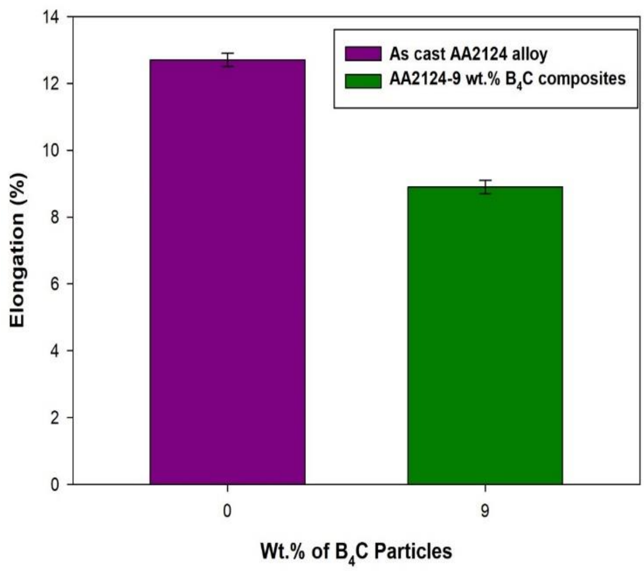

Figure 10. Showing the error graph for percentage elongation of AA2124 alloy-9 wt% B_4C composites.

of 9 wt% of micro boron carbide particles in the AA2124 alloy is 35.42%. Further, there is an improvement in the yield strength of AA2124 alloy, the yield strength of AA2124 alloy is 150.33 MPa. After the addition of 9 wt% of boron carbide particles, it is found 203.7 MPa. The development in quality is credited on account of genuine contact between the matrix structure and materials [14]. Better the grain gauge better is the hardness and nature of composites provoking to upgrade the wear opposition additionally. The improvement in UTS and YS is credited to the closeness of hard B_4C particulates, which presents quality to the structure amalgam, along these lines giving improved unbending nature. The extension of these particles may have offered climb to immense waiting compressive nervousness made in the midst of solidifying due to differentiate in coefficient of advancement between adaptable lattice and particles [15]. The non-shearable nano boron carbide particles increase the strength level of AA2124 alloy due to the interaction of dislocations with increase in wt.% from 0 to 9 wt%. Similar observations were made by Reddy *et al.* [26] in the A356 alloy with nano SiC reinforced composites.

3.5 Percentage elongation

Figure 10 shows the effect of micro B_4C content on the elongation (malleability) of the composites. It tends to be seen from the diagram that the adaptability of the composites decreases basically with the 9 wt% B_4C sustained composites. This reducing in rate of elongation in connection with the base matrix is a most often happening method in particulate metal cross section composites [15,16]. The reduced ductility in composites can be credited to the closeness of B_4C particulates which may get broke and have sharp corners that make the composites slanted to confined split begin. Suresh *et al.* [27] conducted the mechanical characterization of AA7075 alloy reinforced with the nano Al_2O_3 and SiC ceramic particulate composites; found that percentage elongation of the AA7075-Al_2O_3-SiC nano composites is minimum.

3.6 Bending strength

Figure 11 is indicating the bending strength of AA2124 alloy and 9 wt% of B_4C reinforced composites. From the plot it is revealed that the bending strength of AA2124 alloy increases with the addition of micro B_4C particles. The bending strength of as cast AA2124 alloy is 126.1 MPa, the addition of B_4C particles enhanced strength of AA2124 alloy. After the incorporation of B_4C particles in the AA2124 alloy, the bending strength is 172.8 MPa in AA2124-9 wt% B_4C composites. This improved bending strength in the AA2124 alloy is mainly due to the presence of micro size B_4C particles. These micro particles act as a barrier for the deformation of soft Al matrix during loading [16].

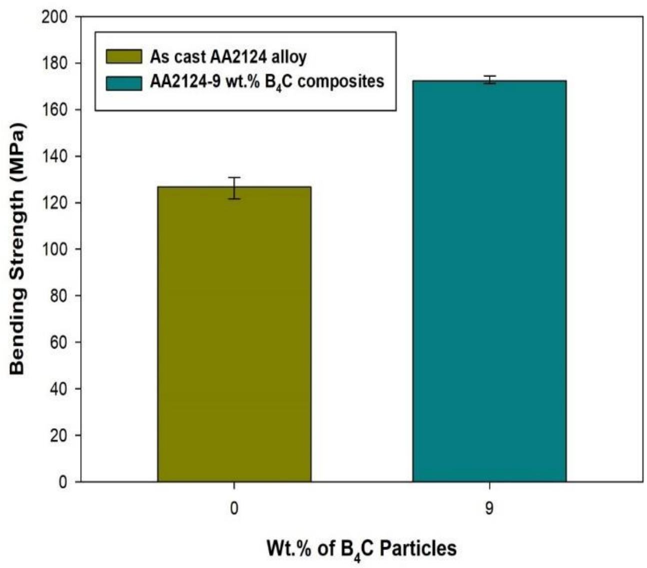

Figure 11. Showing the error graph for bending strength of AA2124 alloy and 9 wt% B_4C composites.

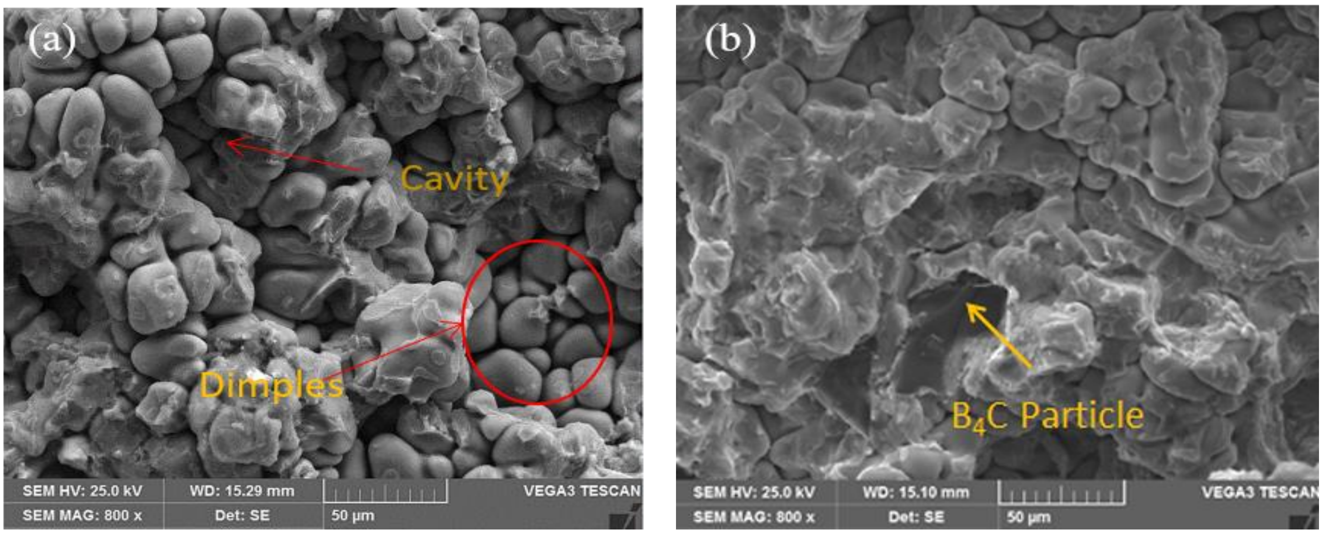

Figure 12. Showing the tensile fractured specimens of (a) AA2124 alloy and (b) AA2124-9 wt% B_4C composites.

3.7 Fracture studies

Tensile fracture of as cast compound and composite examples after tensile testing were examined by utilizing SEM pictures of crack surfaces (Figure 12(a-b)). The as cast AA2124 compound fracture mode is a ductile crack mode as appeared in Figure 12(a), which has extensive number of dimple structures with large number of cavities.

Figure 12(b) demonstrates that 9 wt% B_4C strengthened MMCs crack structures have less ductile failure. Amid ductile test it is acknowledged that particle splitting alongside network material crack, de-holding between the boron carbide particles and Al lattice composite interface are a portion of the explanations behind disappointment MMCs [17]. Little voids saw on account of 9 wt% B_4C composites, broke surfaces demonstrated local stresses at the interfaces is more thus break at support particles mechanism is observed [18].

3.8 Wear behaviour

The wear tests are conducted on the AA2124 alloy and its micron size B_4C reinforced composites at varying loads of 10 to 40 N in steps of 10 N at 400 rpm constant sliding speed and for a sliding distance of 3000 m. Similarly, experiments were conducted at varying sliding speeds of 100 to 400 rpm in steps of 100 rpm at constant 40 N load and 3000 m distance. For all the tests the wear is noted in terms of height loss in micro-meter (μm).

The load is one of the significant parameters which plays important role in wear loss. 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 10, 20, 30 and 40 N at constant distance of 3000 m and speed of 400 rpm. Figure 13 shows the effect of load on the wear behaviour of AA2124 alloy and 9 wt% of B_4C reinforced composites.

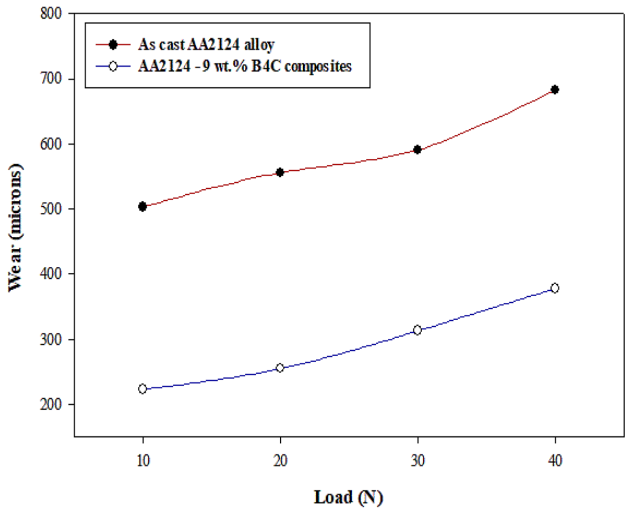

Figure 13. Showing the wear of AA2124 alloy and its B_4C reinforced composites at varying loads and constant sliding speed.

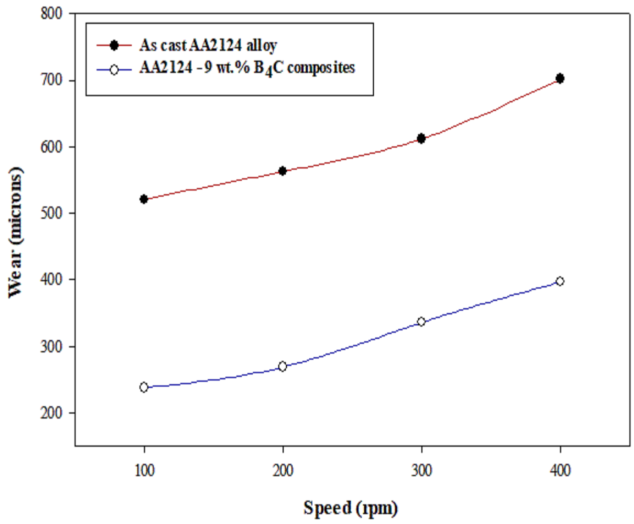

Figure 14. Showing the wear of AA2124 alloy and its B_4C reinforced composites at varying speeds and constant load.

From Figure 13, it is observed that as load increases from 10 to 40 N, there is increase in wear for all the composites and base AA2124 alloy. At maximum load of 40N the temperature of sliding surface and pin exceeds the critical value. Therefore, as the load increases on the pin there is also increase in the wear loss of the matrix AA2124 alloy and AA2124 alloy-9 wt% B_4C composites. The wear loss of as cast AA2124 alloy is highest in all the loading conditions & is represented in the Figure 13. It is seen that the wear loss of the composites decreases with 9 wt% of reinforcement in the AA2124 alloy. The increase in wear resistance of the AA2124 alloy-9 wt% B_4C composites may be due to the high hardness of B_4C particulates which acts as the barrier for the wear loss [19].

Figure 14 shows the wear loss with the variation of speed for several test samples with varying compositions. The test is conducted with varying disc speed of 100, 200, 300 and 400 rpm by retaining load of 40 N. From Figure 14, it is concluded that volume of wear loss increases with the increasing sliding speed. For base AA2124 alloy the effect of sliding speed is more when compared to B_4C based composite.

From Figure 14, it is observed that speed increases from 100 to 400 rpm, there is increase in wear for all the composites and base AA2124 alloy. Although at all the sliding speeds, the wear loss of the composites is much lower, when compared with the AA2124 alloy matrix and is much lesser in the case of AA2124 alloy-9 wt% B_4C composites. Basically, with increase in B_4C particulates the wear loss of the composite decreases in wear loss. Additionally, as sliding speed is kept increasing there is increase in wear loss also because of softening of the composite at increased temperature due to rubbing action. The increase in temperature resulting due to higher sliding speeds also leads to plastic deformation of the test piece [20]. Therefore, there is increased delamination contributing to enhanced wear loss. The results obtained in present work are similar & are in line with the previous research work carried out by other researchers [21,22].

It's significant to study the worn-out surface morphology of AA2124 alloy & its 9 wt% of B_4C reinforced composites as it shows the type of wear the materials with different composition have undergone. During sliding the AA2124 alloy matrix is softer than the rubbing disk material & hence shows viscous flow of AA2124 matrix, which is in the form of pin causing plastic deformation of the specimen surface, resulting in very high material loss. The worn surface of AA2124 alloy shows presence of grooves, micro-pits and fractured oxide layer as shown in Figure 15(a), which would have caused the increase of wear loss. Whereas B_4C particles in AA2124-9 wt% composites restrict the viscous flow of the matrix as shown in Figure 15(b), it is observed that the grooves or erosion have reduced with increase in B_4C particles means there is more and more resistance to wear loss [23]. Meanwhile, the stress seems to be transferred on B_4C particles and strain concentration occurs around these B_4C particles and worn surface area shows less and less cracks and grooves with increasing B_4C particles [24].

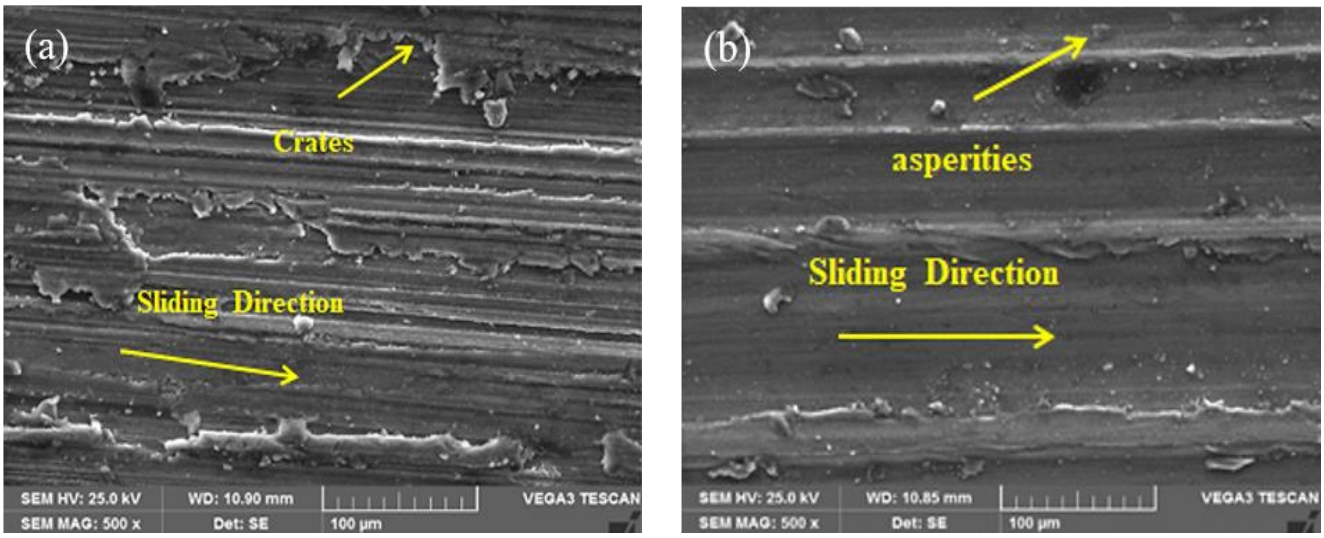

Figure 15. Showing the scanning electron micrographs of worn surfaces of (a) as cast AA2124 alloy and (b) AA2124-9 wt% B_4C composites.

4. Conclusions

In this study, AA2124-B_4C micro composites have been manufactured by stir casting technique by taking 9 wt% of B_4C particles. The microstructure, hardness, UTS, yield quality, elongation, bending strength and wear behaviours of AA2124 alloy and 9 wt% B_4C composites were examined. The framework or composite is free from pores and uniform dispersion of nano particles, which is apparent from SEM microphotographs. The EDS and XRD examination affirm the nearness of B_4C particles in the AA2124 matrix. The mechanical properties of AA2124 and 9 wt% B_4C composites are improved as compared to Al matrix material. The tensile fractured surfaces of the composite material indicate ductile and brittle fracture in Al matrix and its composites respectively. Further, wear resistance of aerospace alloy AA2124 increased with the presence B_4C particles. The improved wear resistance is exhibited by the SEM images of worn surface.

Disclosure of ethical standards

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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