Madeva Nagaral[1], V. Bharath[2], Virupaxi Auradi[2]

MECHANICAL CHARACTERIZATION AND FRACTOGRAPHY OF Al7049-B_4C METAL COMPOSITES

KARAKTERIZACIJA MEHANIČKIH OSOBINA I FRAKTOGRAFIJA Al7049-B_4C METALNIH KOMPOZITA

Originalni naučni rad / Original scientific paper
UDK /UDC:

Rad primljen / Paper received: 21.04.2020

Adresa autora / Author's address:
[1] Aircraft Research & Design Centre, HAL, Bangalore, Karnataka, India email: madev.nagaral@gmail.com
[2] Department of Mechanical Engineering Siddaganga Institute of Technology, Tumkur, Karnataka, India

Keywords
- Al7049 alloy
- B_4C particulates
- microstructure
- tensile strength
- fractography

Abstract

In the current investigation, the microstructure, and mechanical properties of Al7049-4 and 8 wt. % of 80-90 micron size B_4C particulate reinforced composites are displayed. The composites containing 4 and 8 wt. % of B_4C in Al7049 alloy are synthesized by liquid metallurgy method. For the composites, fortification particles are preheated to a temperature of 400°C and afterward added in ventures of two into the vortex of liquid Al7049 alloy compound to improve the wettability and dispersion. Microstructural examination was carried out by SEM, EDS and XRD. Mechanical properties of as cast Al7049 alloy and Al7049-4 and 8 wt. % of B_4C composites are evaluated as per ASTM standards. Microstructural characterization by SEM and EDS confirmed the distribution and presence of micro B_4C particles in the Al7049 alloy matrix. Presence of B_4C phase is confirmed by the XRD patterns. The hardness, ultimate, yield and compression strength of Al7049 alloy are enhanced with the incorporation of 4 and 8 wt. % of micro B_4C particles. Further, ductility of Al7049 alloy has decreased with the presence of B_4C particles. Fractography is studied on tested samples to know the various fracture mechanisms.

Ključne reči
- legura Al7049
- uključci B_4C
- mikrostruktura
- zatezna čvrstoća
- fraktografija

Izvod

U ovom istraživanju su prikazani mikrostruktura i mehaničke osobine Al7409 legura sa 4 i 8 % uključaka B_4C, veličine 80-90 mikrona, koje služe kao ojačanje. Kompoziti sa 4, odnosno 8 % B_4C u leguri Al7049 su sintetizovani tehnikom mešanja u tečnom stanju. U okviru ove metode, ojačavajući uključci su predgrejani do temperature 400°C, nakon čega su ubačeni u parovima u vrtlog tečne legure Al7049, kako bi se poboljšalo kvašenje i disperzija. Mikrostruktura je ispitana primenom SEM, EDS i XRD metoda. Mehaničke osobine livene legure Al7049 i kompozita ove legure sa 4 i 8 % B_4C su određene prema ASTM standardima. Karakterizacija mikrostrukture primenom SEM i EDS metoda je potvrdila prisustvo i raspodelu mikročestica B_4C u matrici legure Al7049. Prisustvo B_4C faze je potvrđeno XRD difraktogramima. Tvrdoća, zatezna i pritisna čvrstoća, kao i granica tečenja legure Al7049 su poboljšani ubacivanjem 4 i 8 % B_4C mikročestica. Osim toga, duktilnost legure Al7049 je smanjena u prisustvu ovih mikročestica. Fraktografija je analizirana na ispitanim uzorcima kako bi se identifikovali mehanizmi loma.

INTRODUCTION

Composite materials are a class of distinctly important materials that have found their place in almost all the engineering applications today. Composite materials can be defined as a combination of two or more phases with identical properties which can be tailored to obtain a unique material system of desired properties /1, 2/.

Composite materials are obtained by ‘combining a matrix- (metal, ceramic, or polymer) and a reinforcement phase (particulates, whiskers, or fibers) using suitable process methodology that ensures uniform dispersion and better characteristics’.

Metal matrix composites are a unique subset of composite materials that have the reinforcements dispersed in the metal matrix phase /3/. Some of the matrix phases used for metal matrix composites are aluminium, copper, magnesium, nickel and cobalt based alloys, /4/.

However aluminium metal matrix composites are predominantly finding their applications in a variety of aerospace and automobile components, /5/. Hence, a lot of research is being carried out in the domain of aluminium metal matrix composites particularly for aerospace applications.

Aluminium metal matrix composites offer quite a lot of advantages as compared to other metal matrix composites in the very fact that they are lightweight and have enormous strength (high strength to weight ratio) and are easily deformable to the required shape and size, /6/. However, fatigue, corrosion, and wear are a matter of concern for aluminium matrix composites, that facilitates the need for developing a new aluminium composite subsystem which will eventually enhance its dynamic characteristics and make it more wear resistant.

The effect of reinforcement is a major aspect to consider for analysing metal matrix composites and its characteristic behaviour under different parameters and circumstances /7/. The major challenge in this regard is the selection of the reinforcement and its composition. Several researchers investigated various properties of metal matrix composites using different reinforcement materials in Al alloys /8, 9/. Al7049 alloy is an aerospace wrought aluminium alloy. This alloy is widely used for machined parts as wing route fittings, heavy bulkheads and landing gear attachment brackets of an aircraft. One can think about the weight reduction point of view in the aerospace domain. Always monolithic alloys like Al7049 usually require larger cross sectional area to have more strength. Hence, it is badly required to enhance the properties of this alloy with minimum cross sectional area, so that weight reduction of the aerospace component is achieved. In the present study an attempt is made to develop Al7049 alloy reinforced B_4C composites.

Based on the available literature, a minimal research is carried out by using 80 to 90 micron sized B_4C particulates in Al7049 alloy matrix. Al7049-B_4C metal matrix composite is prepared by stir casting route. K_2TiF_6 salt is used to increase the wettability of B_4C in Al matrix. B_4C particles are added to aluminium melt in two steps to avoid agglomeration. The prepared AMMC are then subjected to various mechanical tests.

EXPERIMENTAL DETAILS

Materials used

Al7049 alloy is wrought alloy, which can be performed as a secondary operation. Al7049 has the melting point of 660°C and density of 2.82 g/cm^3, and copper is the major alloying element. The Al7049 alloy is mainly used in transport applications and aerospace industry, etc. Al7049 has good toughness, high corrosion resistance, and high elevated temperature strength with good self-healing capacity during welding process. The chemical composition of Al7049 is shown in Table 1.

Table 1. Chemical configuration of Al7049 alloy.

Elements	Si	Fe	Cu	Mg	Cr	Zn	Ti	Mn	Al
wt. (%)	0.25	0.3	1.8	2.3	0.10	8.0	0.10	0.2	Bal.

The reinforcement material is boron carbide which is 80 to 90 μm in size procured from Speedfam Chennai Ltd., India. The reinforcement colour is black. Reinforcement particulate density is 2.52 g/cm^3 with melting point 3300°C and hardness is 3100-3600 kg/mm^2. Figures 1 and 2 are the scanning electron micrograph (SEM) and EDS spectrum of B_4C particles used to prepare the metal composites.

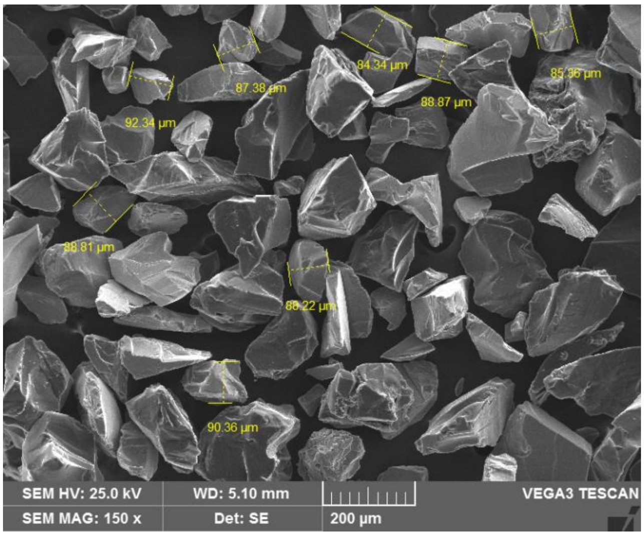


Figure 1. SEM micrograph of B_4C particles.

Methodology and testing

Stir casting process is used for the fabrication of Al7049-B_4C composites. A measured quantity of Al7049 alloy is placed in a graphite crucible. The crucible is then placed inside the electric furnace. The furnace is maintained at 750°C to melt the base matrix material Al7049 alloy. At the same time B_4C particulates are heated in a separate oven at 300°C to remove moisture content and increase wettability. A degassing agent, hexachloroethane, is added to the molten metal to avoid unwanted gases, /10/. The reinforcement of a known quantity of B_4C particulates is poured into the molten metal by novel two-step reinforcement addition method. Then, a mechanical stirrer made of zirconium coated material stirs for 5 minutes at 300 rpm for a homogenous casting mixture. Immediately the molten metal is poured into the die. The die is made up of cast iron, of 120 mm length and a diameter of 15 mm. The process is repeated for other wt. % of B_4C particulate reinforced composites. The castings are machined as per ASTM standards to carry out the required tests. Figure 3 is the stir casting setup used to prepare the Al7049-B_4C composites. Figure 4 demonstrates the prepared composites for the study.

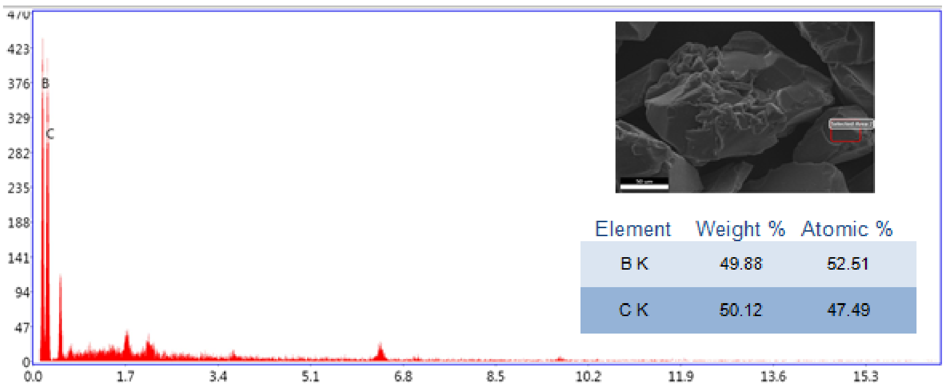


Figure 2. EDS spectrum of B_4C particles.

Figure 3. Stir casting setup (courtesy of Sai Ram College of Engineering, Chennai).

Figure 4. Al7049-B_4C composite after casting.

After casting, the specimen is prepared for microstructural study using SEM to know the uniform distribution of reinforcement particulates B_4C present in the Al7049 alloy. Microstructure images are taken for Al7049 alloy and Al7049-B_4C composites. Specimen sizes for microstructure tests are 15 mm in diameter and 5 mm in height. The specimen surface is grinded by 300, 600 and 1000 grit paper. The surface is polished with 3 μm thickness polishing paper for further smooth finish. The specimens are then cleaned by distilled water to remove foreign particles like dirt and any other impurities if so present on the polished surface. To achieve a contrast surface, the specimens are etched by Killers reagent, /4/.

As per the ASTM standard E10, the specimen is machined accordingly for hardness testing on Brinell hardness tester machine. Specimen surface is smooth polished. A ball indentation of 5 mm is taken and 250 kg load is applied on the specimen. A total of 5 indentation marks are taken on the surface of the specimen, and the results are evaluated.

The size of the indentations on the specimen are observed through optical microscope to compute the hardness value by relation:

$$\mathrm{BHN} = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}, \qquad (1)$$

where: P is the load (kg); D is diameter of steel ball (mm); and d is the size of the indentation.

The presence of porosity in the specimen results in the density measurement. Theoretical values for base alloy and for Al7049-B_4C composites are calculated by rule of mixture. By Archimedean method the experimental values of density are calculated as per ASTM D792. Figure 5 shows the density specimen used to estimate experimental density.

Figure 5. Density test specimen.

Specimens are machined as per the ASTM standard E8 /11/ to study the tensile behaviour of as-cast Al7049 alloy and B_4C reinforced composites. For accurate results, three specimens are taken for tensile strength. The computer controlled tensile machine is used to check the tensile strength as well as to analyse the effect of uniform distribution and investigate Al7049-B_4C composite behaviour in unidirectional tension. The size of the specimen is 104 mm in overall length; gauge length is 45 mm, with 9 mm gauge diameter. With this tensile test, the mechanical behaviour of as cast alloy and composites is evaluated by ultimate and yield strength, and also elongation. Figure 6 shows the tensile test specimen.

Figure 6. Tensile test specimen.

RESULTS AND DISCUSSION

Microstructural studies

Figure 7a-c is the SEM of as-cast Al7049 alloy with 4 and 8 wt. % of B_4C particulate reinforced composites. Figure 7a is the SEM image of the Al7049 alloy, indicating clear grain boundaries without any particles present. The micrograph is clear of voids or any other casting defects. Figures 7b and 7c are micro photos of Al7049-4 wt. % of B_4C and Al7049-8 wt. % of B_4C composites, respectively. From the micrographs it is evident that 4 and 8 wt. % B_4C reinforced composites contain the B_4C particles, as visible in the micrographs. These particles are free from clustering and agglomeration due to the novel two step stir casting process adopted to synthesize the composites. Further, the Al7049-8 wt. % of B_4C composite microstructure surface contains a higher number of B_4C particles, and these particles are distributed all over the surface of the matrix Al7049 alloy.

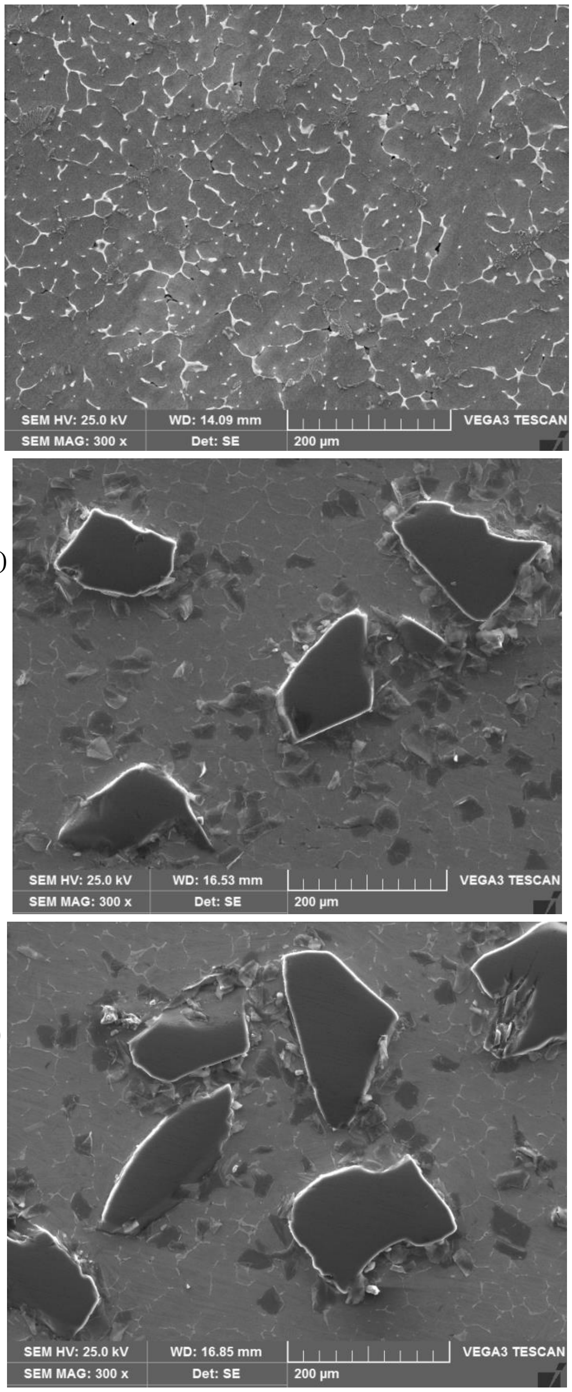
(a)
(b)
(c)


Figure 7. SEM of: a) as-cast Al7049 alloy; b) Al7049-4 wt. % B_4C; c) Al7049-8 wt. % B_4C composites.

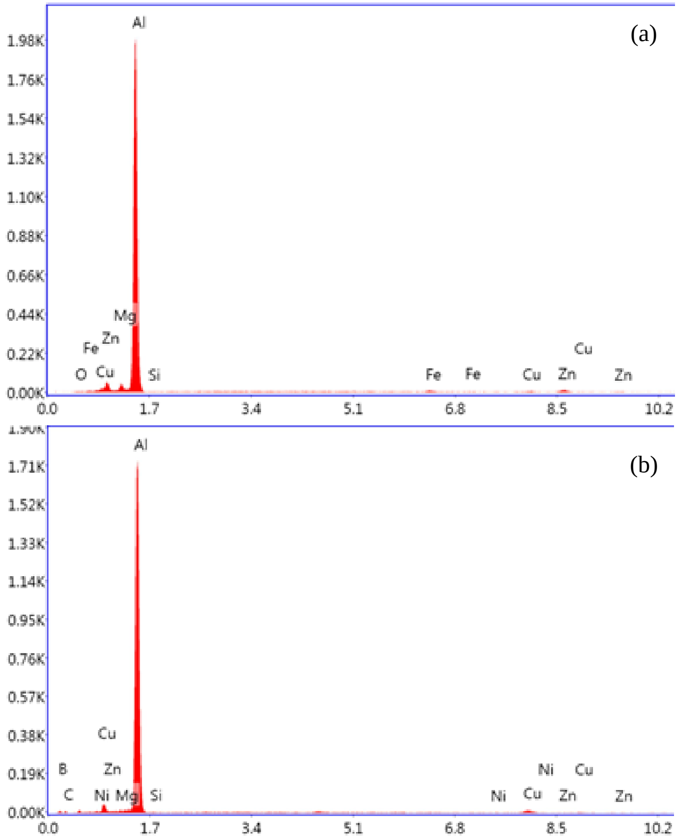


Figure 8. EDS spectrum of: a) as cast Al7049 alloy; b) Al7049-8 wt. % of B_4C composites.

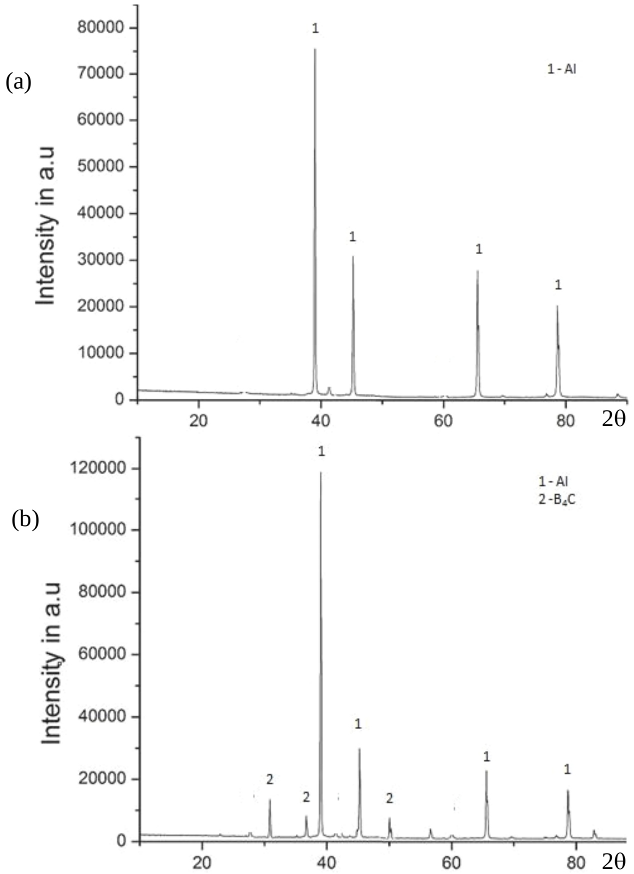


Figure 9. XRD patterns of: a) as cast Al7049 alloy; b) Al7049-8 wt. % B_4C composites.

Figure 8a-b shows the EDS spectrum of as-cast Al7049 alloy and 8 wt. % B_4C particulate reinforced composites. From Fig. 8a it is evident that Al7049 alloy contains Zn as a major alloying element along with Si, F. and Mg. Further, Fig. 8b demonstrates the EDS spectrum of Al7049-8 wt. % B_4C particulate reinforced composites. The EDS spectrum of composites exhibits the presence of B_4C particles in the Al7049 alloy in the form of elements B and C. This presence of B and C elements along with Zn, Mg, Fe and Si confirms the soundness of casting methodology adopted to synthesize the composites.

XRD analysis is carried out on the Al7049 alloy and Al7049-8 wt. % B_4C composite by using the X-ray diffractometer at BMS College of Engineering, Bangalore. Figure 9a is the XRD pattern of Al7049 alloy; usually aluminium phases are available at various peaks. Presence of Al phases are confirmed at 39°, 45°, 65° and 79° with various intensities. The highest intensity of Al phase is observed at 39°. Further, Fig. 9b is the XRD pattern of Al7049-8 wt.% B_4C particulate reinforced composites. Figure 9b indicates various phases as Al and B_4C. As mentioned above, Al phases are widely available at different 2θ angle with variable intensities, and B_4C particle phases are identified at 31°, 38° and 50° with different intensities.

Density measurements

The densities of Al7049 alloy, Al7049 with 4 and 8 wt. % B_4C particulate reinforced composites are presented in Fig. 10. Theoretical densities of Al7049 alloy and the B_4C reinforced composites are computed with the help of rule of mixture. Further, experimental densities are practically determined as per Archimedean concept. The theoretical density of Al7049 alloy is 2.82 g/cm^3, and 2.52 g/cm^3 for B_4C particles. From Fig. 10 it is noted that as wt.% of B_4C particles increases from 4 to 8 wt.% in the Al7049 matrix, the density of the base alloy has decreased from 2.82 to 2.793 g/cm^3. This decreased density with the incorporation of B_4C particles is due to lower density of B_4C particles in comparison with the Al matrix. This high density of reinforced particles makes an improvement in the overall alloy matrix density. Further, from the graph, experimental densities are slightly lower than theoretical densities, and also the difference between both densities is minimal. Theoretical density of Al7049 alloy matrix is 2.82 g/cm^3 and experimental density is 2.691 g/cm^3, this indicates the importance of the casting method adopted to prepare the composites.

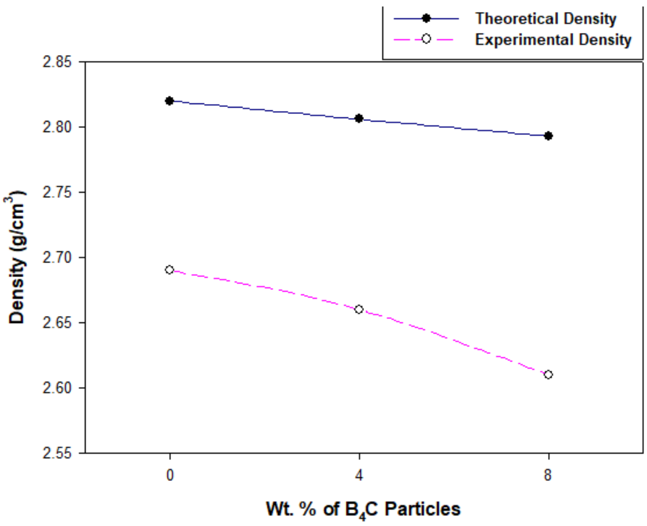


Figure 10. Theoretical and experimental densities of Al7049-B_4C composites.

Hardness measurements

The hardness of Al7049 alloy, Al7049-4 and 8 wt.% B_4C reinforced composites is presented in Fig. 11. The plot demonstrates that as wt.% of B_4C particles increases from 4 to 8 wt.%, there is an enhancement in the hardness of Al7049 alloy. The hardness of as-cast alloy is 64.9 BHN, and after incorporation of 2 and 4 wt.% of TiC particles it becomes 66.1 BHN and 89.4 BHN, respectively. Al7049 alloy-8 wt. % of B_4C composites exhibited 35.3 % improvement in the hardness. An enhancement in the hardness of Al7049 alloy is due to the presence of hard B_4C particles in the ductile matrix. The hardness of B_4C particles is 3500 BHN, and an addition of such a high hardness material into the soft matrix ultimately helps in enhancement of the hardness. Further, due to the thermal coefficient mismatch between Al7049 alloy and B_4C particulates creates the dislocation density. This process rises the strain hardening within the composites, /12/, and the strain hardening phenomena increases the hardness of the composites.

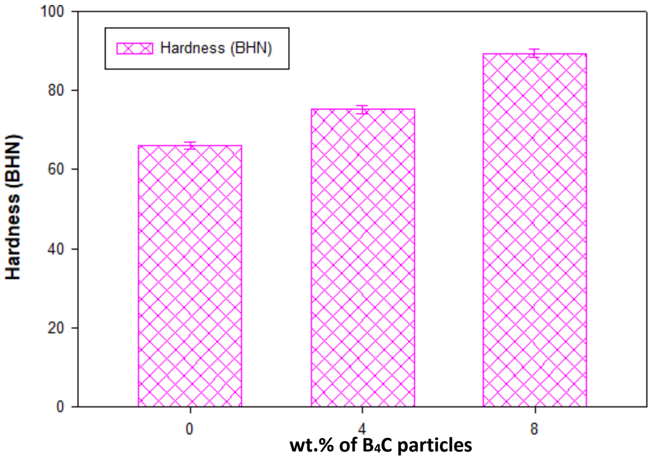


Figure 11. Hardness of Al7049 alloy and B_4C reinforced composites.

Ultimate tensile- and yield strength

The influence of B4C particles on the ultimate strength of Al7049 alloy is denoted in the Fig. 12. From the Fig. 12 it is indicated that as the wt. % of B4C particles increases in the soft Al matrix, the strength of Al7049 alloy has been enhanced. The ultimate tensile strength of Al7049 alloy is 227.8 MPa. Further, the UTS of Al7049-4 wt. % of B4C and Al7049-8 wt. % of B4C composites are 246.3 MPa and 289.2 MPa, respectively. An improvement of 26.9% in the UTS of Al7049 alloy has obtained after the incorporation of 8 wt. % of 80 to 90 micron sized B4C particulates.

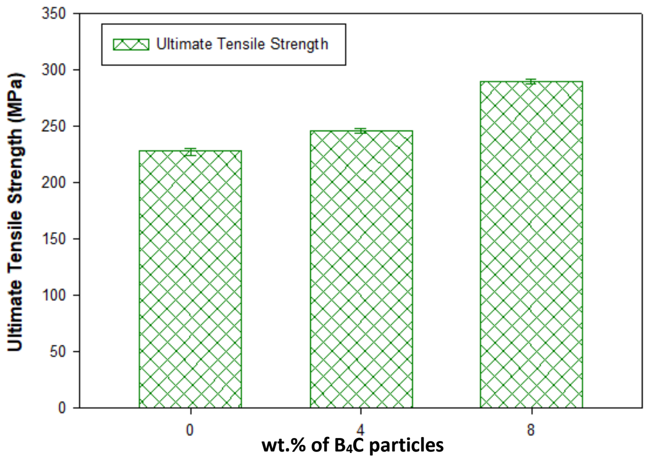


Figure 12. Ultimate strength of Al7049 alloy and B_4C reinf. composites.

The influence of B_4C particles on ultimate strength of Al7049 alloy is denoted in Fig. 12. From Fig. 12 it is indicated that as the wt.% of B_4C particles increases in the soft Al matrix, the strength of Al7049 alloy is enhanced. Ultimate tensile strength (UTS) of Al7049 alloy is 227.8 MPa. Further, the UTS of Al7049-4 wt.% of B_4C and Al7049-8 wt.% of B_4C composites are 246.3 and 289.2 MPa, respectively. An improvement of 26.9 % in the UTS of Al7049 alloy is obtained after the incorporation of 8 wt.% of 80 to 90 micron sized B_4C particulates.

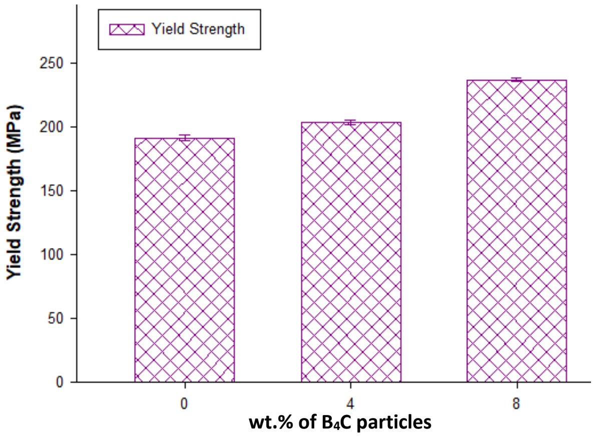


Figure 13. Yield strength of Al7049 alloy and B_4C reinf. composites.

The influence of B_4C particles on the yield strength of Al7049 alloy is denoted in Fig. 13. From Fig. 13 it is indicated that as the wt.% of B_4C particles increases in the soft Al matrix, the strength of Al7049 alloy is enhanced. The yield strength of Al7049 alloy is 191.6 MPa. Further, the yield strength of Al7049-4 wt.% B_4C and Al7049-8 wt.% B_4C composites are 203.4 and 237.1 MPa, respectively. An improvement of 23.7 % in the UTS of Al7049 alloy is obtained after incorporation of 8 wt.% of 80 to 90 micron sized B_4C particulates.

From plots in Figs. 12 and 13 it is noticeable that both ultimate and yield strength of Al7049 alloy are enhanced with 4 and 8 wt.% B_4C particles. The increase in strength of Al alloy is due to B_4C presence in the matrix. The hard particle makes the soft matrix brittle and resistant to higher directional loads. These hard particles act as load carrying elements in the composites, which helps improve the strength of composites. Further, as per the Hall-Petch strengthening mechanism with the addition of micro particles in the Al matrix decreases the grain size, this reduction in grain size of the composites contributes to increased strength of the material. The thermal mismatch between Al7049 alloy and B_4C particles is high; this expansion coefficient mismatch produces the density dislocations as per the Orowan principle, /13/. The formed density dislocations generate strain hardening within the Al-B_4C melt and result in the development of a higher strength.

Percentage elongation

Figure 14 indicates the ductility of the Al7049 alloy and Al7049 alloy with 4 and 8 wt.% of micro B_4C particulate reinforced composites. According to the plot, ductility decreases with increasing content of B_4C particles in the matrix. The decrement in the ductility is attributed to the availability of hard B_4C particles in the matrix, the strong multidirectional stresses in the Al7049 alloy-B_4C interface avoids more elongation of the material. The sound bonding between the Al and B_4C particles, and the effective transfer of applied load to the even distributed higher number of B_4C micro particles. Hence, with all these effects, the elongation obtained in the Al7049 alloy - 8 wt.% B_4C composites is lesser as compared to base matrix with 4 wt.% B_4C particle reinforced composites.

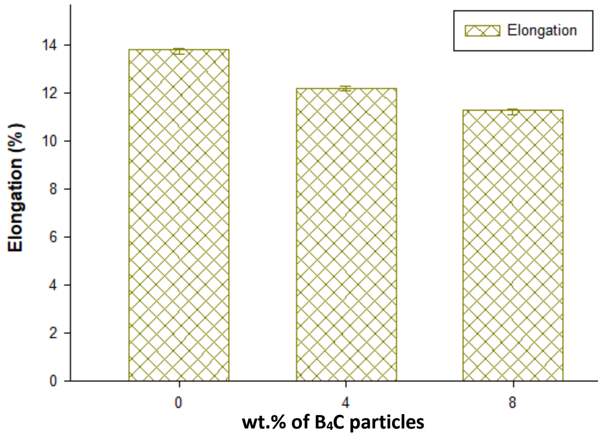


Figure 14. Percent. elong. of Al7049 alloy and B_4C reinf. composites.

Compressive strength

The compression strength of Al7049 alloy and Al7049 alloy with 4 and 8 wt.% of B_4C particle reinforced composites are shown in Fig. 15. From the plot it is determined that presence of hard particle phase enhances the compression strength of Al7049 alloy matrix, and it increases further as weight % of B_4C particles increases. Always, the strength of carbide or oxide particles is notified by compressive strength as these ceramics are harder in nature. This strength of the Al-B_4C composites can be attributed to the significant amount of grain refinement obtained with the addition of B_4C particles, the presence of evenly distributed harder elements, and dislocation generated due to the modulus mismatch and thermal expansion coefficient /14/. According to the results obtained from Fig. 15 it can be noticed that the effect of B_4C content on the compressive strength is considerable. This confirms the obvious effect of B_4C particles on the strengthening of Al-B_4C composites.

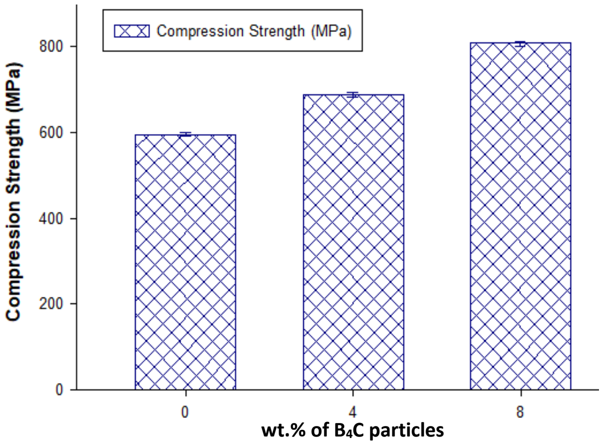


Figure 15. Compress. strength of Al7049 alloy and B_4C reinf. compos.

Fractography

Figure 16a-c illustrates the SEM photographs of the fracture surfaces of Al7049 alloy and Al7049 alloy with 4 and 8 wt.% B_4C particle reinforced composites. From all the tensile fractured micrographs, it can infer that there is good bonding between the matrix alloy and the B_4C reinforcement. Figure 16a shows the fractured surface on 200× magnification images of the Al7049 alloy. The fractured surface of as-cast alloy represents the ductile fracture with a clear visibility of grains.

(a)

(b)

(c)

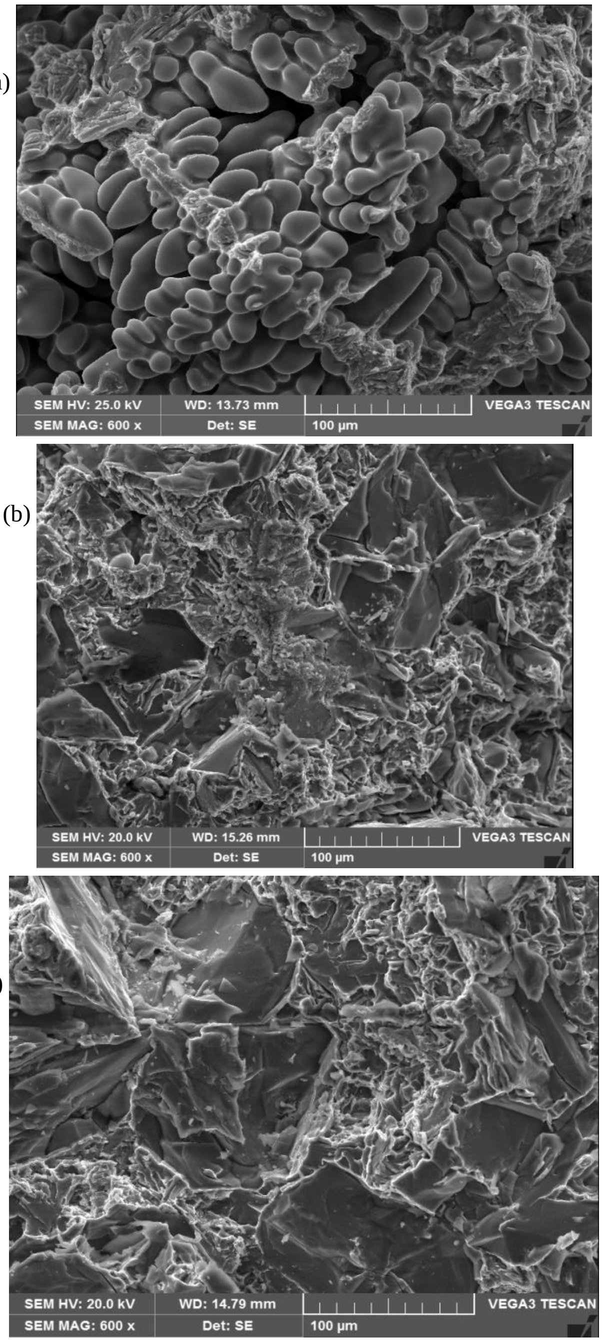


Figure 16. Tensile fractured surfaces on SEM images of: a) as-cast Al7049 alloy; b) Al7049-4 wt.% B_4C; c) Al7049-8 wt.% B_4C composites.

Further, Fig. 16b-c are the fractured surfaces of Al7049-4 wt.% of B_4C and Al7049-8 wt.% of B_4C composites. According to the micrographs, as the B_4C reinforcement increases, there is increased brittleness of the composites. This increased brittleness is clearly visible in the tensile fractured surface of Al7049-4 wt.% of B_4C composites. Further, this brittle fracture is directly co-related with the elongation of the composites. As discussed in the percentage elongation section, there is decrease in the ductility of the composites as wt.% of B_4C particles increases.

CONCLUSIONS

The Al7049-B_4C metal composites are effectively synthesized using stir casting method with the metallurgical process. Microstructural characterization of the prepared Al7049 alloy and Al7049 alloy with 4 and 8 wt.% B_4C composites is analysed by SEM/EDS and XRD patterns. The distribution and presence of B_4C micro particles in the Al7049 alloy is demonstrated by SEM micrographs, EDS analysis, and respective XRD patterns. The Al7049-B_4C composite density gradually improves as the B_4C percentage increases 4 to 8 wt.%. It is noted from the outcomes that as the micro B_4C content expands in the Al7049 alloy, there is enhancement in the ultimate-, yield-, and compressive strength with nominal reduction in ductility. Tensile fractured surfaces exhibit the ductile mode fracture in unreinforced material. Further, as the reinforcement content rose to 8 wt.%, a brittle mode fracture is observed in the composites.

REFERENCES

1. Nagaral, M., Auradi, V., Kori, S.A. (2015), *Microstructure and mechanical properties of Al6061-graphite composites fabricated by stir-casting process*, Appl. Mech. Mater. 766-767: 308-314. doi: 10.4028/www.scientific.net/AMM.766-767.308
2. Manjunatha, T.H., Basavaraj, Y., Venkataramana, V., Nagaral, M. (2018), *The effect of heat treatment on mechanical properties of aluminium alloy 7075 with nano B_4C*, Emerg. Trends in Mech. Eng.: Select Proc. of ICETME 2018, L. Vijayaraghavan, K. Hemachandra Reddy, S.M. Jameel Basha (Eds.), Springer, pp.481-488. doi: 10.1007/978-981-32-9931-3_46
3. Pathalinga Prasad, G., Chittappa, H.C., Nagaral, M., Auradi, V. (2019), *Effect of the reinforcement particle size on the compressive strength and impact toughness of LM29 alloy-B_4C composites*, Struct. Integ. and Life, 19(3): 231-236.
4. Nagaral, M., Auradi, V., Kori, S.A., Hiremath, V. (2019), *Investigations on mechanical and wear behavior of nano Al_2O_3 particulates reinforced AA7475 alloy composites*, J Mech. Eng. Sci. 13(1): 4623-4635. doi: 10.15282/jmes.13.1.2019.19.0389
5. Jadhav, P.R., Sridhar, B.R., Nagaral, M., Harti, J.I. (2020), *Mechanical behavior and fractography of graphite and boron carbide particulates reinforced A356 alloy hybrid metal matrix composites*, Adv. Compos. Hybrid Mater. 3: 114-119. doi: 10.1007/s42114-020-00143-7
6. Nagaral, M., Auradi, V., Kori, S.A., Shivaprasad, V. (2020), *Mechanical characterization and wear behavior of nano TiO_2 particulates reinforced Al7075 alloy composites*, Mech. Adv. Compos. Struct. 7(1): 71-78. doi: 10.22075/MACS.2019.17075.1194
7. Jadhav, P., et al. (2018), *A comparative study on microstructure and mechanical properties of A_{356}-B_4C and A_{356}-graphite composites*, Int. J Mech. Prod. Eng. Devel. 8(2): 273-282.
8. Ramakoteswara Rao, V., Rangaraya Chowdary, J., Kumar Gudapati, S.P. (2020), *Fabrication and investigation on mechanical properties of (AA7075/Cr_3C_2) metal matrix composites*, Mater. Today Proc. 23(3): 513-517. doi: 10.1016/j.matpr.2019.05.397

9. Uppada Rama Kanth, Putti Srinivasa Rao, Mallarapu Gopi Krishna (2019), *Mechanical behaviour of fly ash/SiC particles reinforced Al-Zn alloy-based metal matrix composites fabricated by stir casting method*, J Mater. Res. Technol. 8(1): 737-744. doi: 10.1016/j.jmrt.2018.06.003
10. Kumar, D., Singh, P.K. (2019), *Microstructural and mechanical characterization of Al-4032 based metal matrix composites*, Mater. Today Proc. 18(7): 2563-2572. doi: 10.1016/j.matpr.2019.07.114
11. Nagaral, M., Nayak, P.H., Srinivas, H.K., Auradi, V. (2019), *Characterization of tensile fractography of nano ZrO_2 reinforced copper-zinc alloy composites*, Frattura ed Integrità Strutturale, 13(48): 370-376. doi: 10.3221/IGF-ESIS.48.35
12. Fazil, N., Venkataramana, V.V., Nagaral, M., Auradi, V. (2018), *Synthesis and mechanical characterization of micro B_4C particulates reinforced AA2124 alloy composites*, Int. J Eng. Technol. 7(2.23): 225-229. doi: 10.14419/ijet.v7i2.23.11954
13. Bharath, V., Madeva, N., Auradi, V., Kori, S.A. (2014), *Preparation of 6061 Al-Al_2O_3 MMC's by stir casting and evaluation of mechanical and wear properties*, Procedia Mater. Sci. 6: 1658-1667. doi: 10.1016/j.mspro.2014.07.151
14. Nagaral, M., Kalgudi, S., Auradi, V., Kori, S. (2018), *Mechanical characterization of ceramic nano B_4C-Al2618 alloy composites synthesized by semi solid processing*, Trans. Indian Ceramic Soc. 77(3): 146-149. doi: 10.1080/0371750X.2018.1506363