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EFFECT OF THE REINFORCEMENT PARTICLE SIZE ON THE COMPRESSIVE STRENGTH AND IMPACT TOUGHESS OF LM29 ALLOY-B_4C COMPOSITES

UTICAJ VELIČINE ČESTICE OJAČANJA NA PRITISNU ČVRSTOĆU I UDARNU ŽILAVOST LM29-B_4C KOMPOZITNE LEGURE

Originalni naučni rad / Original scientific paper
UDK /UDC: 669.75.018

Rad primljen / Paper received: 29.07.2019

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Keywords

- LM29 alloy
- micro B_4C
- melt stirring
- microstructure
- strength, toughness

Abstract

Investigations are made on the effect of 40 and 90 μm sized B_4C particulate addition on compressive strength and impact toughness of LM29 alloy. Micro B_4C particulates of 40 and 90 μm are used as reinforcements in the Al alloy matrix. Composites are prepared by using liquid melt method in steps of 3, 6 and 9 wt.% in the LM29 alloy. Samples are tested for microstructural characterization by using scanning electron microscope (SEM) and energy dispersive spectroscope (EDS). Mechanical properties as hardness, compression, and toughness are evaluated as per ASTM standards. SEM micrographs reveal the uniform distribution of B_4C particulates in the LM29 alloy and are confirmed by EDS analysis. Further, compression and impact strength of base matrix LM29 alloy is enhanced with the addition of B_4C reinforcement and is more evident in the case of 40 μm size reinforced composites.

Ključne reči

- legura LM29
- mikro B_4C
- mešanje rastopa
- mikrostruktura
- čvrstoća, žilavost

Izvod

U radu su predstavljena istraživanja o uticaju ojačavajućih čestica B_4C od 40 i 90 mikrona na pritisnu i udarnu čvrstoću legure LM29. Mikro B_4C čestice od 40 i 90 mikrona su primenjene za ojačavanje matrice legure Al. Kompoziti su pripremljeni korišćenjem metode tečnog rastopa u fazama 3, 6 i 9 tež. % u leguri LM29. Uzorci su ispitivani karakterizacijom mikrostrukture primenom skening elektronskog mikroskopa i disperznog spektroskopa. Mehaničke osobine kao što su tvrdoća, ponašanje pod pritiskom i udarna čvrstoća su određene prema standardu ASTM. Skening elektronski mikro foto snimci otkrivaju uniformnu raspodelu čestica B_4C u leguri LM29 što je potvrđeno i EDS analizom. Pritisna i udarna čvrstoća matrične osnove legure LM29 su poboljšane dodatkom ojačanja B_4C, a posebno u slučaju ojačavanja česticama kompozita od 40 mikrona.

INTRODUCTION

Aluminium is widely used in aerospace, automobile and structural applications due to its advantageous properties like light weight, low density, corrosion resistance, high specific strength, high stiffness, cost effectiveness, etc., when compared to existing metals being used, . The density of aluminium is about one-third of iron and copper and the corrosion resistivity eliminates the need of protective coatings. Recent expansion in research indicates that there is still a large scope progress in the aluminium usage. The application of aluminium with improved properties will meet economic and ecological demands, /1, 2, 3/.

Aluminium metal matrix composites (AMMC) can be processed by various routes as liquid metallurgy, solid metallurgy, in situ methods etc., but due to low cost, simplicity in processing and better properties, liquid metallurgy is selected. Wettability of ceramic particles is the main problem that is faced in processing AMMC and can be overcome by coating of reinforcement, which is one of the techniques to increase the wettability, /4/. To increase the wettability of B_4C, coating it with Ti has yielded better results. K_2TiF_6 halide salt is mixed uniformly with B_4C during casting and has resulted in better bonding between Al and B_4C, and also in better mechanical properties by forming the Ti layer around B_4C particles, /10/. B_4C and graphite is mixed with aluminium by using the mechanical stirrer. Use of a mechanical stirrer and rigorous stirring helps in the homogeneous distribution of particulates in the metal matrix. Two-step addition of reinforcing particulates is adopted in liquid metallurgy which helps in the homogeneous distribution and to overcome the agglomeration of particulates /6, 8, 9/.

In general aluminium based MMCs offer a substantial increase in elasticity modulus and strength over the unreinforced alloys and often accompanied by large reduction in percentual elongation. Properties of composites are affected by the reinforcement particle size, shape and volume fraction of the reinforcement, matrix material, and reaction at the interface, /5, 7, 14/.

However, minimal information is available regarding the compressive and impact properties of the LM29 reinforced with micro B_4C particulates MMC's processed by stir casting method. With the increasing demand of lightweight materials in the emerging industrial applications, the aluminium-boron carbide composites play an important role, especially in the aerospace domain. Keeping the above observations in view, it is proposed to develop LM29 micro B_4C composites with varying particle size and weight percentages of B_4C particulates. In this study, investigated are mechanical properties of LM29 alloy-based composites with 40 and 90 micron-sized B_4C particulates by varying weight percentages, like 3, 6 and 9 wt.% by using liquid metallurgy technique.

EXPERIMENTAL DETAILS

Materials used

Table 1. Chemical composition of LM29 alloy.

Elements	Si	Cu	Mg	Ni	Al
wt. %	24.0	1.0	1.0	1.0	bal

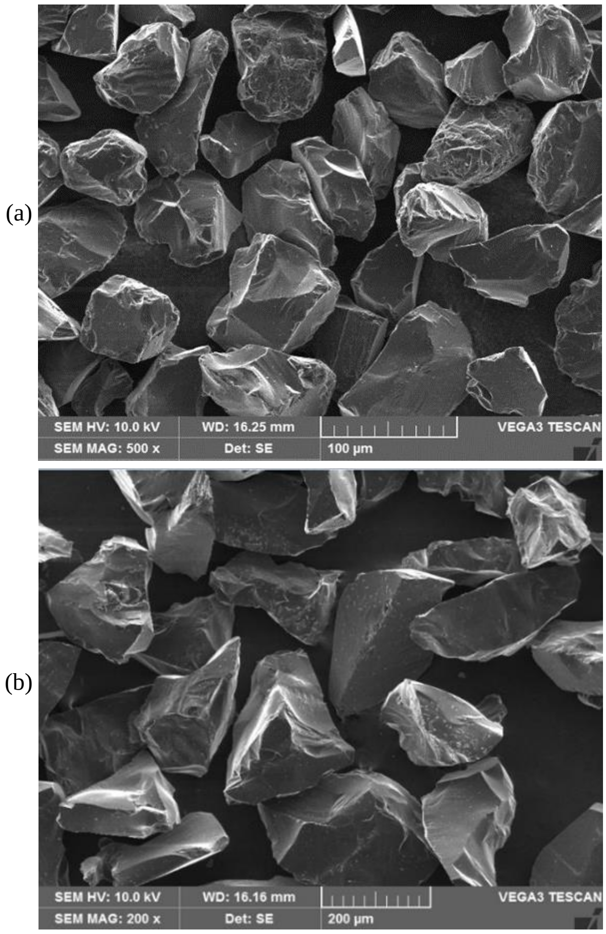


Figure 1. SEM micro photograph of: (a) 40 μm B_4C; (b) 90 μm B_4C.

Metal matrix composites containing 3, 6 and 9 weight percentages of B_4C particulates with 40 and 90 μm size are produced by liquid metallurgy route. For the production of MMCs, an LM29 alloy is used as the matrix material while B_4C particles with an average size of 40 and 90 μm are used as reinforcements, as shown in Fig. 1. The chemical composition of the alloy used in the investigation is given in Table 1.

Preparation of composites

The fabrication of LM29-B_4C composites with 40 and 90 μm sized particles are carried out by liquid metallurgy route via stir casting technique. Calculated amount of the LM29 alloy ingots are charged into the furnace for melting. The melting point of aluminium alloy is 660 °C. The melt is superheated to 750 °C. The temperature is recorded using a chromel-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 is rotated at a speed of 300 rpm and the depth of immersion of the impeller is 60 percent of the height of the molten metal from the surface of the melt. Further, B_4C particulates preheated in a furnace up to 600 °C are introduced into the vortex. Stirring is continued until the interface interactions between reinforcement particulates and the matrix promote wetting. Then, the LM29- 3, 6 and 9 wt. % B_4C mixture is poured into permanent cast iron mould having dimensions 120 mm length, and 15 mm diameter. Further, based on the microstructural study, strength and impact toughness are evaluated as per ASTM standards, the and comparison of properties is made between the LM29 alloy-40 micron size B_4C and 90 micron size B_4C reinforced composites. Figure 2a and 2b show the specimens for compression and Charpy impact tests used in the study.

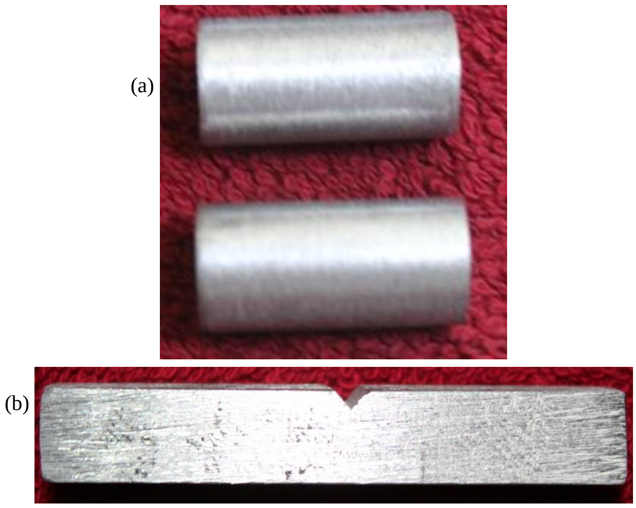


Figure 2. Specimens for: (a) compression; (b) Charpy impact test.

The face of the specimen which must be subjected to microstructural analysis by SEM and EDS to be polished using 220, 400, 600, 800 and 1000 grit emery papers and finally using diamond paste. Keller's regent is used to etch the specimen before it is inspected using SEM and EDS to study the dispersion of particles in the matrix.

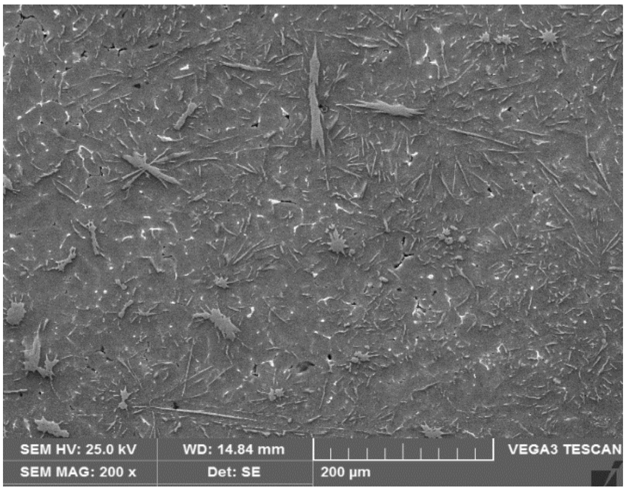
The hardness test is carried out by using the Brinell hardness testing machine as per ASTM E10 standard, by using 5 mm diameter ball indenter and 250 kg load. The compression test is conducted using universal testing machine on three specimens, each of pure LM29 alloy, LM29-3, 6 and 9 wt.% of 40 and 90 μm size B_4C particulate reinforced composites, prepared as per ASTM: E9 standard. The average results of the three specimens for varying composition are noted. The Charpy impact test is conducted by using the impact test machine as per ASTM E23 standard. Fractured specimens in the Charpy impact test are further studied by SEM micro-photo analysis.

RESULTS AND DISCUSSION

Microstructural study

The work accomplished here is an attempt made to develop LM29 aluminium alloy composites reinforced with 40 μm sized boron carbide particulates by liquid metallurgy stir casting technique. Metallographic specimens are prepared through standard procedure of mechanical polishing, and further etching with a Keller's chemical solution, commonly used for Al alloys and its composites. The particle distribution in the LM29 alloy matrix at various fabrication conditions is examined through SEM.

(a)



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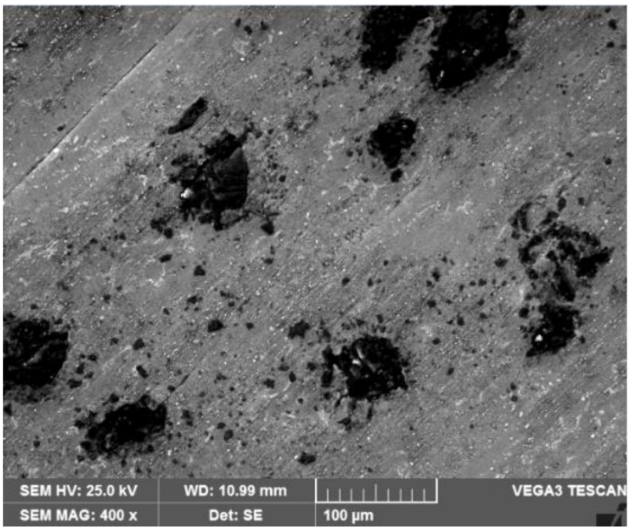

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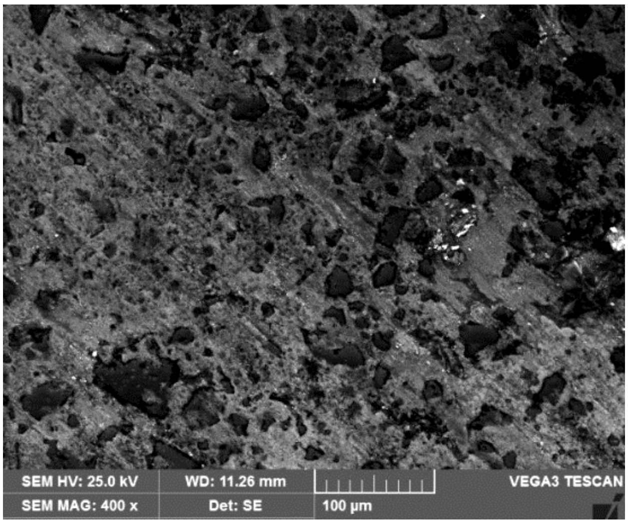

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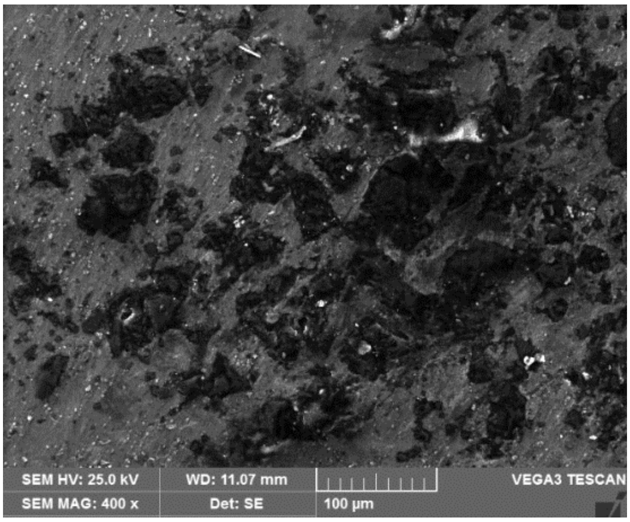
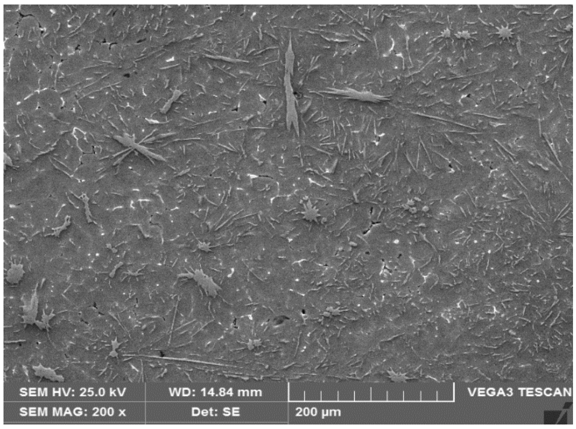


Figure 3. SEM micrographs of LM29 alloy: (a) as cast; (b) 3% B_4C; (c) 6% B_4C (d) 9% B_4C, with 40 μm B_4C particles.

Figure 3a shows the microstructure of as cast LM29 aluminium alloy, Figs. 3b-3d represent LM29 -3 wt.% B_4C, 6 wt.% B_4C, and 9 wt.% B_4C composites with 40 μm sized particles. SEM micrographs reveal almost uniform distribution of B_4C particulates throughout the matrix as observed in Figs. 3b-3d. Uniformly distributed particulates increase the overall strength and other properties, reducing the porosity of the MMC.

(a)



(b)

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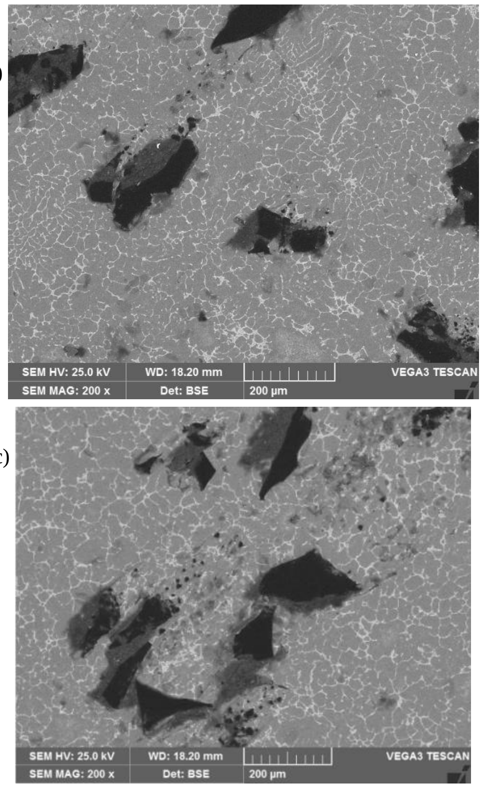

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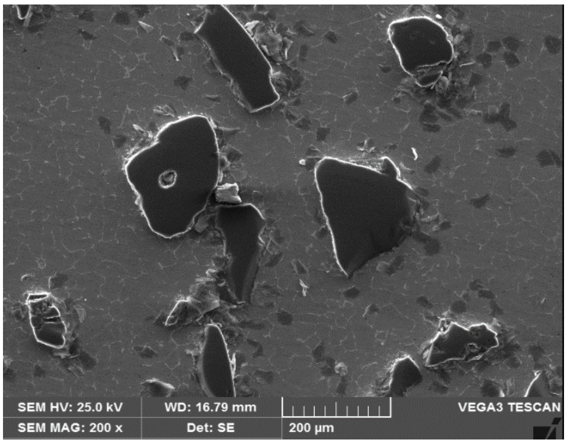

Figure 4. SEM micrographs of LM29 alloy: (a) as cast; (b) 3% B_4C; (c) 6% B_4C; (d) 9% B_4C, with 90 µm B_4C particles.

Figure 4a shows the microstructure of as cast LM29 aluminium alloy. Figures 3b-3d represent LM29- 3 wt.% B_4C; 6 wt.% B_4C; and 9 wt.% B_4C composites with 90 µm sized particles. SEM micrographs reveal almost an uniform distribution of B_4C particulates throughout the matrix as observed in Figs. 4b-4d. Uniformly distributed particulates increase overall strength and other properties, reducing the porosity of the MMC.

Figures 5a-5c show energy dispersive spectrographs (EDS) of as cast LM29 alloy, and LM29-9 wt.% of 40 µm sized B_4C particulates reinforced composites, and LM29-9 wt.% of 90 µm size B_4C reinforced composites. In the composites, the B_4C particle presence is identified by the B and E elements.

(a)

(b)

(c)

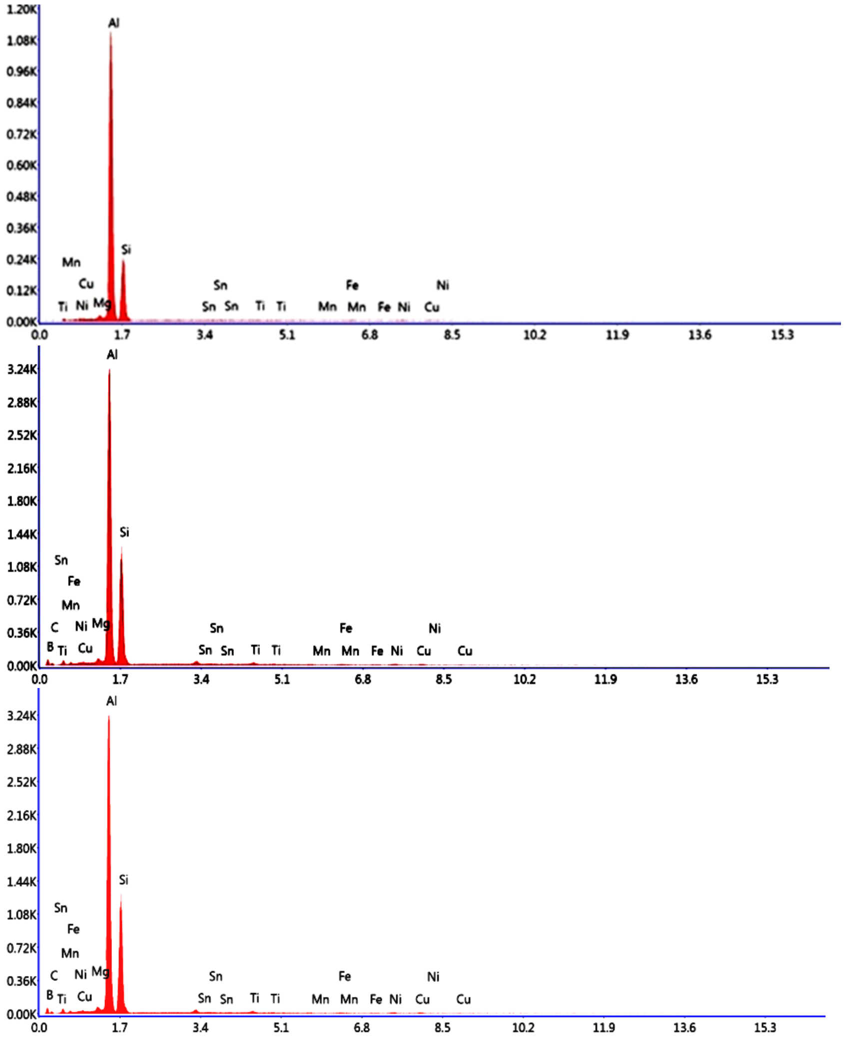

Figure 5. EDS of LM29 alloy: (a) as cast; (b) 9% B_4C with 40 µm B_4C; (c) 9% B_4C with 90 µm B_4C composites.

Hardness measurements

Figure 6 shows the comparison of hardness of LM29 alloy with 3, 6 and 9 weight percentages 40 and 90 micron sized B_4C particulate reinforced composites. From the graph it is evident that as the weight percentage of reinforcement particles increases from 3 to 9 wt.%, there is increase in hardness of LM29 alloy in both 40 and 90 μm sized composites. Further, 40 μm sized B_4C composites exhibit higher hardness values as compared to 90 μm sized B_4C composites. The hardness of base matrix LM29 alloy is 61.9 BHN. After adding 3, 6 and 9 wt.% of 40 mμ sized B_4C particulates, the hardness values are 73.5, 86.2 and 99.4 BHN, in respect. Similarly, in the case of 3, 6 and 9 wt.% of 90 μm sized B_4C particulate reinforced LM29 alloy composites, it is 70.9, 80.4 and 94.9 BHN, in respect. From the values it is noticed that hardness of 40 μm sized B_4C composites is superior than in 90 μm B_4C composites. The enhancement of hardness is more evident in smaller particle reinforced composites. This increase is due to good wettability of particles in the LM29 alloy matrix, /11, 12/, and is noticeable by microstructural studies also. As particle size decreases, the reinforcement bonding increases with the matrix alloy.

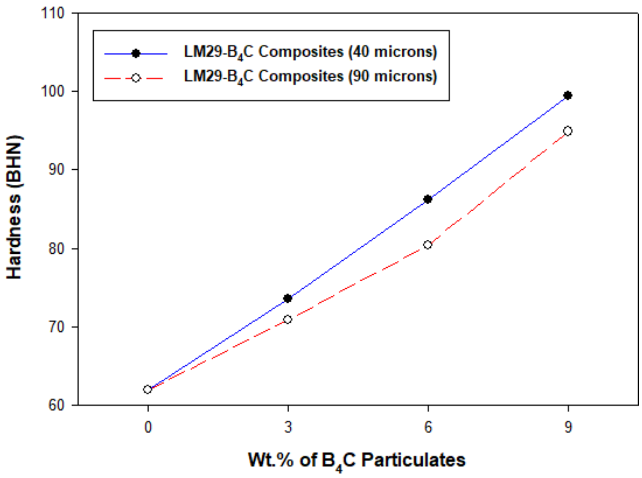

Figure 6. Hardness of LM29 alloy with 40 and 90 μm size B_4C reinforced composites.

Compression strength

Figure 7 shows a comparison of compressive strength of LM29 alloy with 3, 6 and 9 wt.% of 40 and 90 μm B_4C particulate reinforced composites. The compressive strength of LM29 alloy increases after the addition of 40 and 90 μm sized B_4C particles. Further, composites with 40 μm sized B_4C particulates show higher compressive strength as compared to the 90 μm particle reinforced composites.

The compressive strength of LM29 alloy base matrix is 570.6 MPa. Further, the LM29 alloy with 9 wt.% of 40 μm B_4C particle reinforced composites compressive strength is 800.1 MPa, and this is 782.2 MPa in 9 wt.% of 90 μm B_4C particle reinforced composites. This increase is due to superior compressive strength of hard B_4C particles present in the matrix. Further, the more enhanced strength in the 40 μm sized particle reinforced composites, as compared to larger sized particle reinforced composites is due to the high resistance of crushing 40 μm B_4C particles.

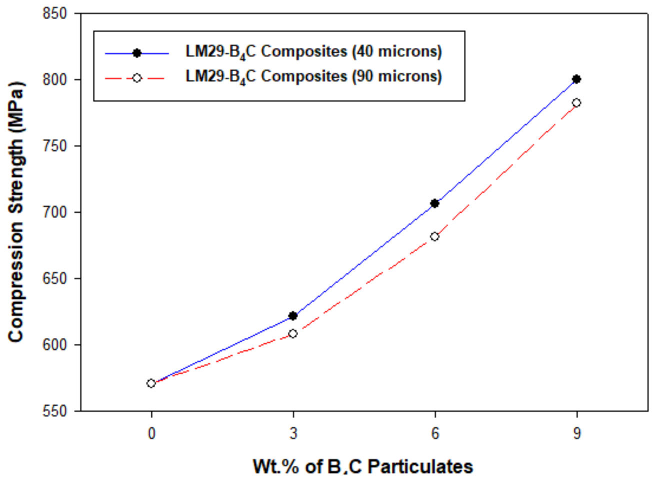

Figure 7. Compression strength of LM29 alloy with 40 and 90 μm size B_4C reinforced composites.

Charpy impact toughness

The comparison of impact toughness of LM29alloy with 40 and 90 μm sized B_4C reinforced composites is shown in Fig. 8. The impact toughness of LM29 alloy is increased in 3 and 6 wt.% of 40 and 90 μm sized particle reinforced composites. LM29 alloy – 9 wt.% of Boron carbide with 40 and 90 μm sized composites shows a slightly decreased impact toughness as compared to the 6 wt.% B_4C particle composites. Further, LM29 alloy with 40 μm B_4C particle reinforced composites exhibits superior impact toughness as compared to 90 μm B_4C particle reinforced composites, and the as-cast LM29 alloy base matrix. The increase of impact toughness in 40 μm B_4C composites is mainly due to the resistance of smaller particles to debond during impact loading. If the impact load is applied to composites with relatively larger particles, the debonding of larger particles is a phenomenon that occurs more frequently, and this reduces impact toughness as compared to smaller sized particles, /13, 15/.

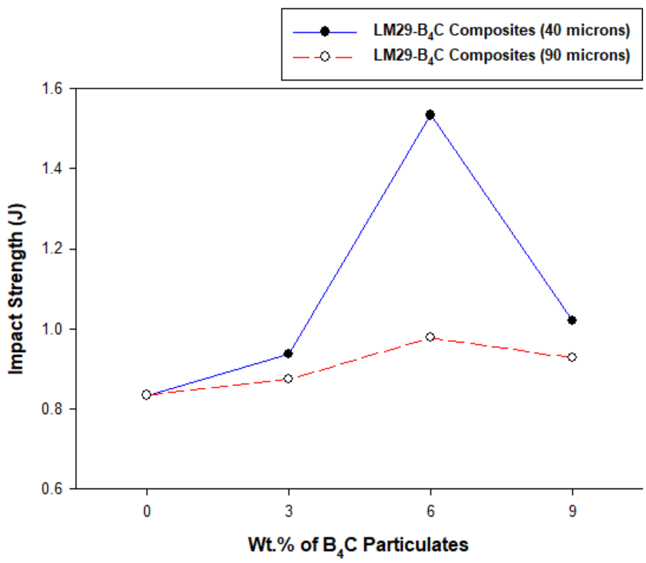

Figure 8. Impact toughness of LM29 alloy with 40 and 90 μm size B_4C reinforced composites.

CONCLUSIONS

Based on this research of the synthesis and characterization of varying size B_4C particulate reinforced LM29 alloy composites, the overall conclusions are as follows:

1. LM29 alloy with 3, 6 and 9 wt.% of 40 micron sized B_4C particulate reinforced composites are successfully fabricated by the stir casting route.
2. LM29 alloy with 3, 6 and 9 wt.% of 90 μm sized B_4C particulate reinforced composites are successfully fabricated by the stir casting route.
3. Energy dispersive analysis (EDS) reveals presence of 40 and 90 μm sized B_4C particles in LM29- B_4C composites in the form of B and C elements.
4. Hardness of LM29 - 3, 6 and 9 wt.% of B_4C composites increases with the addition of 40 and 90 μm sized B_4C particles. Further, 40 μm sized B_4C particle reinforced LM29 alloy composites have higher hardness as compared to 90 μm B_4C reinforced composites, and as-cast LM29 alloy.
5. Improvements in the compressive strength of the LM29 matrix are obtained with the addition of B_4C particulates. Further, the LM29 alloy with 40 μm sized B_4C particulate reinforced composites exhibits superior compressive strength as compared to 90 μm sized B_4C composites.
6. Improvements in Charpy impact toughness of the LM29 matrix is obtained with the addition of B_4C particulates. Further, the LM29 alloy with 40 μm sized B_4C particulate reinforced composites exhibits superior impact toughness as compared to 90 μm sized B_4C composites.

REFERENCES

1. Sajjadi, S.A., Torabi Parizi, M., Ezatpour, H.R., Sedghi, A. (2012), *Fabrication of A356 composite reinforced with micro and nano Al_2O_3 particles by a developed compocasting method and study of its properties*, J Alloys and Compounds, 511(1): 226-231. doi: 10.1016/j.jallcom.2011.08.105
2. Sharma, S., Kini, A., Shankar, G., et al. (2018), *Tensile fractography of artificially aged Al6061-B_4C composites*, J Mech. Eng. Sci., 12(3): 3866-3875. doi: 10.15282/jmes.12.3.2018.8.0 339
3. Zhang, H., Chen, M.W., Ramesh, K.T., et al. (2006), *Tensile behavior and dynamic failure of aluminum 6092/B_4C composites*, Mater. Sci. Eng. A, 433(1-2): 70-82. doi: 10.1016/j.msea.2006.06.055
4. Pakdel, A., Witecka, A., Rydzek, G., et al. (2018), *A comprehensive analysis of extrusion behavior, microstructural evolution and mechanical properties of 6063 Al-B_4C composites produced by semisolid stir casting*, Mater. Sci. Eng.: A, 721: 28-37. doi: 10.1016/j.msea.2018.02.080
5. Wang, W., Du, A., Fan, Y., et al. (2018), *Microstructure and tribological properties of SiC matrix composites infiltrated with an aluminium alloy*, Tribol. Int., 120: 369-375. doi: 10.1016/j.triboint.2018.01.001
6. Sekar, K., Kanjirathikal, A., Joseph, M.A. (2014), *Effect of T6 heat treatment in tribological properties of A356 aluminum alloy reinforced with Al_2O_3 nanoparticles by combination effect of stir and squeeze casting method*, Appl. Mech. Mater. 592-594: 968-971. doi: 10.4028/www.scientific.net/AMM.592-594. 968
7. Radhika, N., Raghu, R. (2014), *Statistical modeling and analysing of wear behaviour of LM25 Al/B_4C/Gr hybrid composite*, Intern. J Appl. Eng. Res. 9(26): 8770-8773.
8. Akhil, K.T., Verghese, J., Raphel, A., et al. (2017), *To study the cooling rate and influence of boron carbide on mechanical properties of aluminium LM13 matrix B_4C reinforced composites*, Mater. Today Proceed. 4(8): 7202-7207. doi: 10.1016/j.matpr.2017.07.047
9. Karabulut, S., Gokmen, U., Cinici, H. (2016), *Study on the mechanical and drilling properties of AA7039 composites reinforced with Al_2O_3/B_4C/SiC particles*, Composites Part B: Eng. 93: 43-55. doi: 10.1016/j.compositesb.2016.02.054
10. Hariprasad, T., Varatharajan, K., Ravi, S., Karthikeyan, C. (2015), *Evaluation of mechanical properties of fly ash-B_4C reinforced Al5083 composites*, Int. J Appl. Eng. Res. 10(9): 7834-7837.
11. Vannan, S.E., Vizhian, S.P. (2014), *Microstructure and mechanical properties of as cast aluminium alloy 7075/basalt dispersed metal matrix composites*, J Miner. Mat. Charact. Eng. 2(3): 182-193.
12. Selvam, J.D.R., Dinharan, I., Philip, S.V., Mashinini, P.M. (2018), *Microstructure and mechanical characterization of in situ synthesized AA6061-(TiB_2+Al_2O_3) hybrid aluminum matrix composites*, J Alloys Compounds, 740, doi: 10.1016/j.jallcom.2018.01.016.
13. Kim, H.H., Babu, J.S.S., Kang, C.G. (2013), *Fabrication of A356 aluminum alloy matrix composite with CNTs/Al_2O_3 hybrid reinforcements*, Mater. Sci. Eng. A, 573: 92-99. doi: 10.1016/j.msea.2013.02.041
14. Khosravi, H., Bakhshi, H., Salahinejad, E. (2014), *Effects of compocasting process on microstructural characteristics and tensile properties of A356-SiCp composites*, Trans. Nonfer. Metals Soc. China, 24: 2482-2488. doi: 10.1016/S1003-6326(14)63374-4
15. Sharma, P., Khanduja, D., Sharma, S. (2014), *Metallurgical and mechanical characterization of Al6082-B_4C-Si_3N_4 hybrid composite manufactured by combined ball milling and stir casting*, Appl. Mech. Mater. 592-594: 484-488. doi: 10.4028/www.scientific.net/AMM.592-594.484