Microstructural and Mechanical Behaviour of Aluminium7175 Alloy Reinforced with Silicon Carbide, Boron Carbide and Graphite

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Abstract: In this paper, the effects of reinforcements on the mechanical behavior of the cast aluminium-based composites are investigated. The reinforcing materials B_4C, SiC, and Graphite with different weight percentages (3%, 6%, 9%, and 12%) are used to fabricate the composites. The composite with 12% by weight exhibits the highest hardness and tensile strength. This paper identified the changes in the behavior of mechanical properties such as tensile strength, hardness, and elongations of the Hybrid Composite & SEM test is used to determine the microstructures of the composite material.

Keywords: Aluminium, Composite, Stir Casting, Fabrication, Reinforcements.

Introduction

The selection of materials for the various components used in automobiles, power plants, sheet metals, and defense sectors is extremely complex and challenging due to fuel economy, safety improvement, overall cost, material availability, energy efficiency, and global warming concerns [1]. Aluminium metal matrix composite (AMMCs) play a crucial role in various fields due to their unique properties. Properties such as good strength-to-weight ratio, high wear resistance low cost are leading to an increase in demand for aluminum-based composites [2, 3]. Numerous processes are available for production of aluminum- based composites. In the liquid phase, the Stir-casting process is widely accepted for the fabrication of aluminium-based composites [5].

A composite is defined as the addition of two or more different phases with different natural properties (physical or chemical) built up in a complex form at all the levels (micro and macro). In the field of material science and engineering, the metal matrix composite is defined as the sum of two or more two different materials or metals, one of which acts as the matrix phase and the other is added in the form of fiber/ powders/particles that constitute the reinforced phase or the second phase, where the matrix phase is made of copper, aluminium, iron or steel [8, 9]. At the same time, the second phase is made of ceramic, carbide, oxide or other metal that plays the role of the reinforcing phase. The metal matrix composite is classified according to the role of the reinforcements such as fibers, powders or particles [11.12].

The metal matrix composite is manufactured with different percentage of reinforcements, When only one reinforcing material is added, the metal matrix composite is referred to as a monolithic composite; when more than two reinforcing materials are added to the matrix, then it is referred to as a hybrid based composite [15].

According to the literature, different researchers have used SiC, B_4C, $ZrSiO_4$, Gr, CaC_2, TiC, and Al_2O_3 with various aluminum alloys to analyze the structural and mechanical properties of composites. Research to develop hybrid composites employing a mixture of (SiC+B_4C+Gr) as reinforcements using AA7175, however, has not yet been conducted. SiC particles are chemically to live with aluminum and successfully connect with in matrix. [16]. SiC is one of the most popular reinforcements for AMCs because of its superior workability, thermal conductivity, good machinability, and inexpensive cost. B_4C is added to aluminum composites to further enhance their mechanical properties. High hardness and stiffness combined with low density make B_4C a suitable reinforcement material according to several mechanical parameters [17]. A variety of techniques are available for the fabrication of composites, including stir casting, infiltration, squeeze casting. The traditional stir casting technique is the method that is frequently used to fabricate composite materials since it can be utilized to create intricate shapes and is also relatively affordable [19, 20].

AMC has been generally used in different industries, including automotive, aerospace, sporting goods, and manufacturing [24]. However, ongoing work has been done to enhance the currently used AMC and create new types for a variety of applications.

In this paper, the effect of reinforcements in AA7175 is investigated in weight percent. The reinforcements (SiC, B_4C, and Gr) with wt. % of (3, 6, 9, and 12) are added by stir casting method.

This article described the production of aluminium metal matrix hybrid composites and improvements in their mechanical properties [25, 26].

2. Materials and Methods

Determination of Reinforcement Compositions

Three reinforcements have been used in this paper, In which total four composite samples have been made, previous researchers had taken different percentages, three reinforcements are mixed in the powder form, the composition of reinforcements is given in the Table 1.

Table 1 shows the three types of reinforcements with different proportions used to produce composite specimens.

Table 1. Reinforcement Compositions

Sr. No.	Material	Reinforcements	Wt%
1.	AA7175	B_4C, SiC, Graphite	(1% B_4C+1% SiC+1% Gr) = 3%
2.	AA7175	B_4C, SiC, Graphite	(2% B_4C+2% SiC+2% Gr) = 6%
3.	AA7175	B_4C, SiC, Graphite	(3% B_4C+3% SiC+3% Gr) = 9%
4.	AA7175	B_4C, SiC, Graphite)	(4% B_4C+4% SiC+4% Gr) = 12%

Table 2 shows the four types of composite specimen compositions. These are some calculations for the creation of composites by stir casting in grams. The total weight of each composite sample is shown in Table 2..

Table 2. Composite Specimen Compositions

Sr. No.	AA7175 wt. %	B_4C wt. %	SiC wt. %	Graphite wt.%	Total wt. in Grams
1	1500gm	15gm	15gm	15gm	1545
2	1500gm	30gm	30gm	30gm	1590
3	1500gm	45gm	45gm	45gm	1635
4	1500gm	60gm	60gm	60gm	1680

Fabrication of AA7175/SiC/ B_4C/Graphite

In this process, the reinforcement usually in powder form are mixed into Aluminium metal matrix and stirred with by stirrer. The flow diagram for development of AMMCs by stir casting is shown in Fig. 2. After completion of process, the melt was poured into a mould of desired shape. Permanent mold casting, die casting or sand casting may be used to obtain the desired shape.

Stir casting process or formation of composite materials. Aluminium sheet of 30mm×60 mm×95 mm of AA7175 series show in Fig. 1(a). The stir casting furnace which is shown in Fig. 1(d) and waited until the temperature reached 500°C. Then putting the aluminium sheet into the crucible and waited further untill the temperature reached 900°C. After that, added all the reinforcing powder from Fig. 1(b) and stirred for 10 minutes so that it could be mix well with the base material and we are able to cast the homogeneous composite. It takes about 4 to 5 hours for a piece of composite to be ready for casting into a rectangular mould and after that we have to wait around 3 hours for the casting to cool down. This process is repeated for all four composite samples.

Aluminium Alloy (AA7175) of 7 series are used. The base metal is melted in the Stir casting furnace and reinforcements are added at 500°C. The mixed molten metal are poured into the casting so that they will regain a rectangular shape and converted into the composite show in Fig. 1(f). Precautions and safety procedures needed to be followed for casting process because it has high temperature of melting metal such as 900°C.

(a)

Boron Carbide

Graphite

(b)

B_4C SiC Gr

(c)

(d)

Fig.1: (a) AA7175, (b) Boron Carbide and Graphite, (c) Reinforcement, (d) Stir Casting

Table 3 shows the values of stir casting parameter employed in the present article. Important Information during the fabrication process is:-

Table 3. Casting Process Parameter

Parameter	**Approx. Value**
Maximum temperature of stirring	900°C
Reinforcement preheat temperature	500°C
Stirrer speed	250 rpm
Time for stirring	10 minutes
Mould preheat temperature	260°C
First casting preparation time	4 hours approx.
Second casting preparation time	2.5 hours approx.
Third casting preparation time	4 hours approx.
Fourth casting preparation time	2.5 hours approx.
Pouring time for the liquid composite into the mould	10 seconds
Cooling time of casted composite	2.5-3 hours

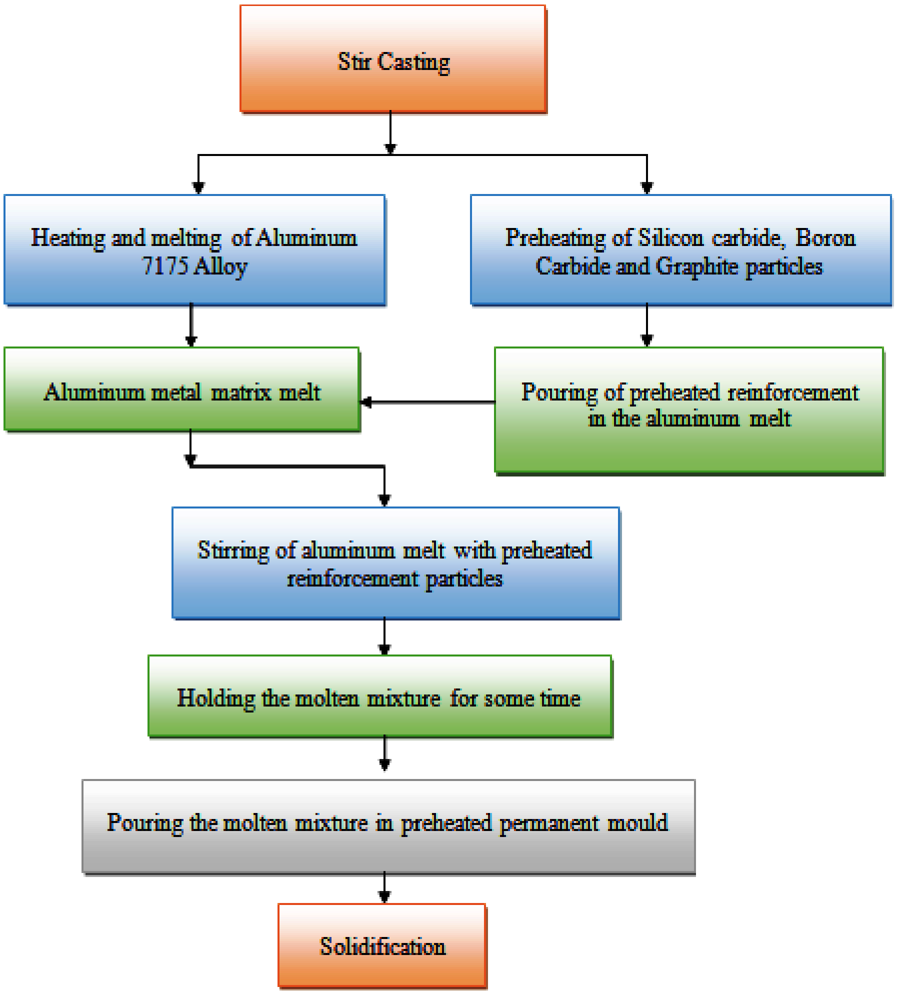


Fig. 2 : Flow Diagram Showing Various Steps of Stir Casting Process

3. Results and Discussion

Mechanical properties like hardness, tensile and elongation values were obtained from the test and some pictures of morphology test were also found.

Hardness Test

Hardness tester is used to determine the hardness of composite. For all four samples i.e. 3%, 6%, 9% and 12%weight of reinforcements, the hardness value obtained are different. One thing that we see is the hardness values increase with the increasing percentage of reinforcements. The tests were conducted at “Global test house pvt.ltd, New Delhi’’ at 250 kgf.

Table 4. Hardness Test

Test	Grade	% of Reinforcement	Result (HB)
Brinell Hardness (HB)	AA7175	3	101.8
Brinell Hardness (HB)	AA7175	6	112.3
Brinell Hardness (HB)	AA7175	9	130.5
Brinell Hardness (HB)	AA7175	12	136.0

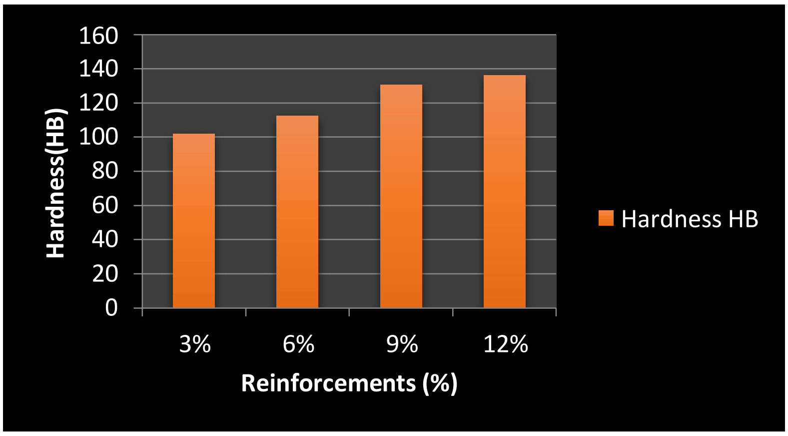


Fig. 3: Variation of Hardness increases with wt% of Reinforcements (SiC, B_4CGraphite)

Tensile Strength Test

To determine tensile strength of the composite, we must perform a tensile test or tensile failure of the composite material. The most commonly used machine is Universal Testing Machine (UTM) but here we test our specimen on the Tensile Testing Machine (TTM) because the length of the specimen was 100mm which is not gripped properly in the UTM jaws, so we chose the TTM because it can grip the material with shorter length [25].

We had already made the shape of the specimen in the standard dumbbell form which could fail or break if the tensile load was applied from the minimum area region. See the results of the tensile strength (MPa) in Table 5.

Table 5. Tensile Test

Test	Grade	% of Reinforcement composition	Results (Mpa)
Tensile Strength (Mpa)	AA7175	3	126.0
Tensile Strength (Mpa)	AA7175	6	151.5
Tensile Strength (Mpa)	AA7175	9	181.0
Tensile Strength (Mpa)	AA7175	12	215.0

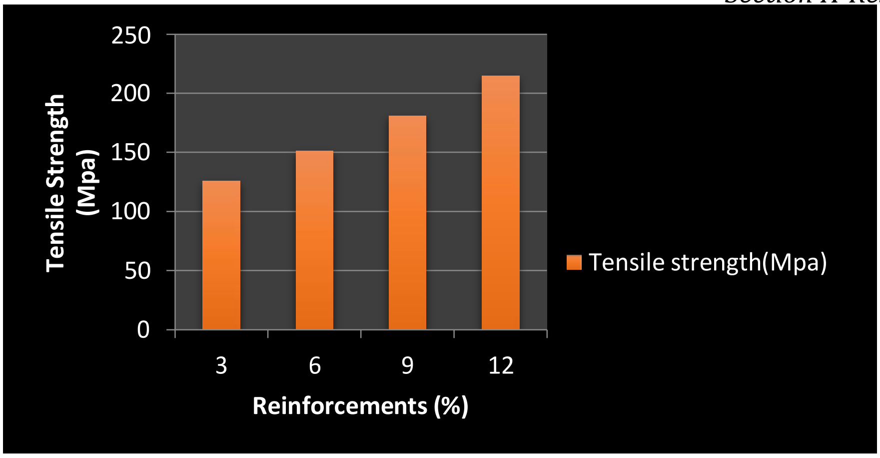


Fig. 4: Variation of Tensile Strength increases with % of Reinforcements.

Elongation Test

During tensile test, we are also interested to find out the elongation percentage of the composite because we want to know that if there is a variation in the elongation of the AA7175 when it has been added with the reinforcement materials. Generally the alloy of aluminium having more percentage of elongation with respect to the composite added with hard reinforcement sees the results in below Table 6.

Table 6: Elongation Test.

Test	Grade	% of Reinforcement composition	Results (%)
Elongation (%)	AA7175	3	2.99
Elongation (%)	AA7175	6	1.62
Elongation (%)	AA7175	9	1.12
Elongation (%)	AA7175	12	1.02

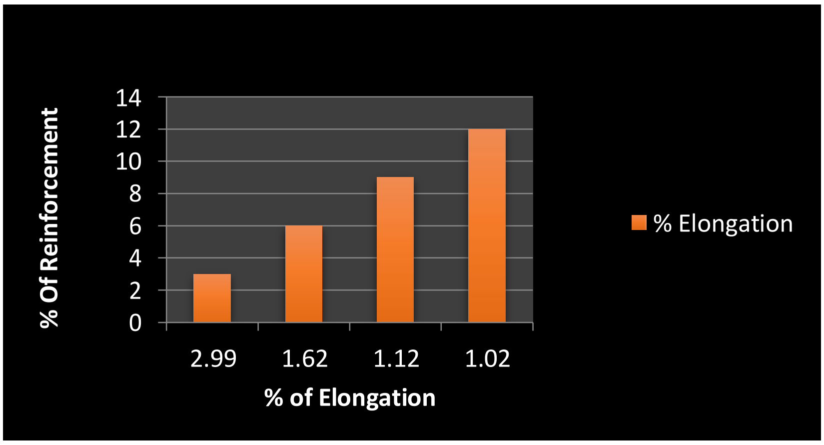


Fig. 5: Variation of Elongation Percentage with Reinforcements.

SEM Test

Scanning electron microscopy is utilised to determine the microstructure of material. In this process, the sample is scanned with electrons overall surfaces. All images show the particle distributions of all the metallic and non-metallic elements. Fig. 6(a) shows the image of first sample which contains the 3% weight of three reinforcements. In which three homogeneous, some areas of the image consist the agglomerated particles. Fig. 6(b) and Fig. 6(c) shown uniformed distributions of SiC, B_4C, and Graphite particles, In which some cracks and voids are found. Fig. 6(d) shows the different particle distributions of reinforcement contents.

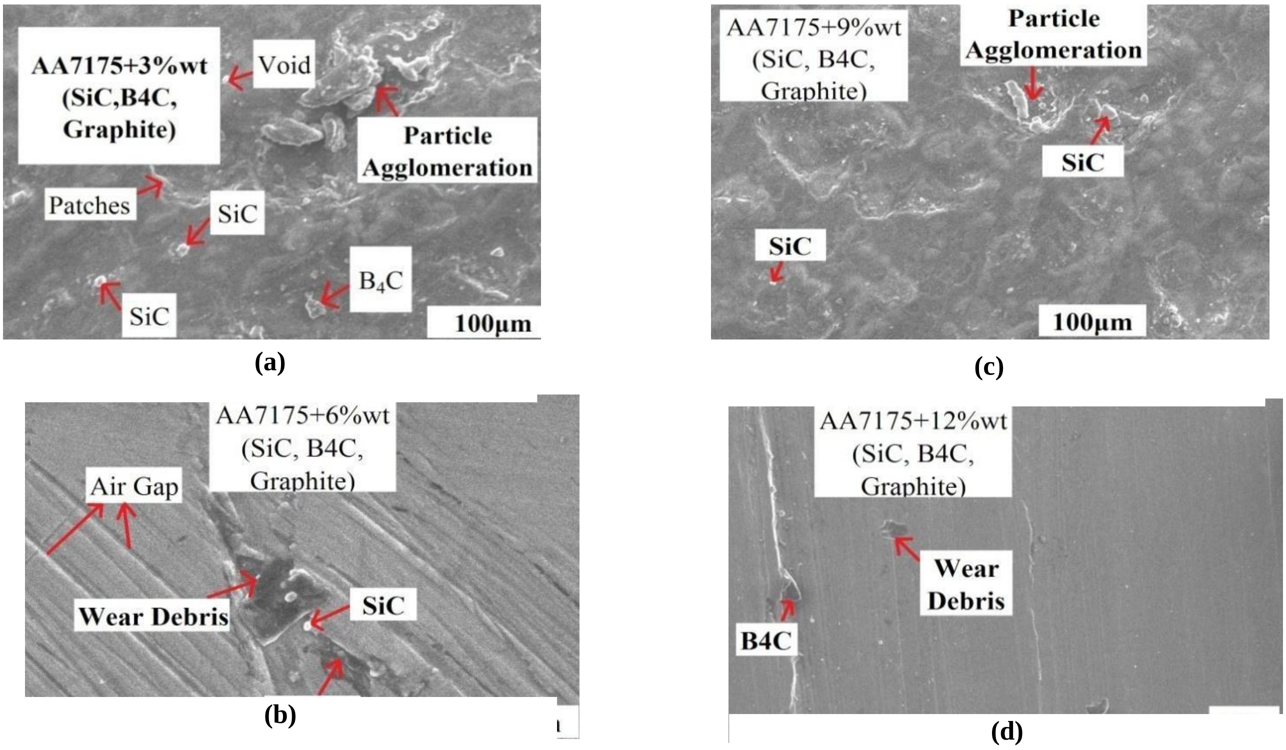


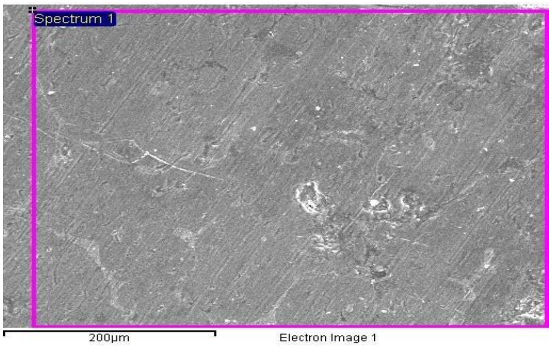
Fig. 6: SEM Images (a) 3% of SiC/ B_4C/ Gr (b) 6% SiC/B_4C/Gr (c) 9% of SiC/ B_4C/ Gr (d) 12% of SiC/B4C/ Gr

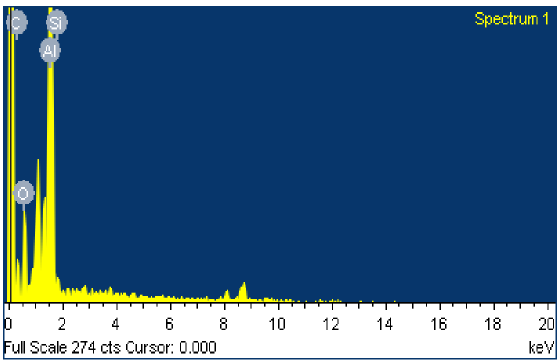
Fig.6 shows the Scanning Electron Microscopy micrograph of four specimens at 200X magnifications. Particle agglomerations, air gap, wear debris, and patches are formed.

EDX Test

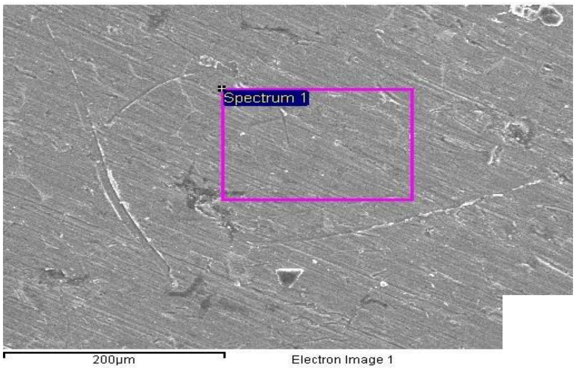
In Figure 6, the EDX results are shown. The EDX analysis of the AA7175/SiC/B_4C/Gr four samples of (3, 6, 9, 12) wt% images are shown. There are relatively low intensity oxygen peaks. The EDX investigation shows that composites are very well shielded against ambient oxygen entrapment throughout the fabrication process. This is because the stirring was done through a small hole that was made on the top of the furnace and the melting was done in a closed chamber. Carbon (C), aluminium (Al), silicon (SiC) and B_4C particles, which are found in composite specimens, are visible in the spectrum. It has been discovered that as reinforcement is increased, the content peaks of C and SiC also rise, leading to an excellent dispersion of reinforcement particles in the Al matrix.

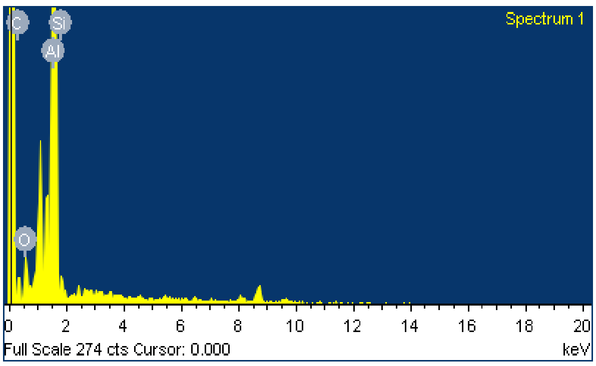
(a)

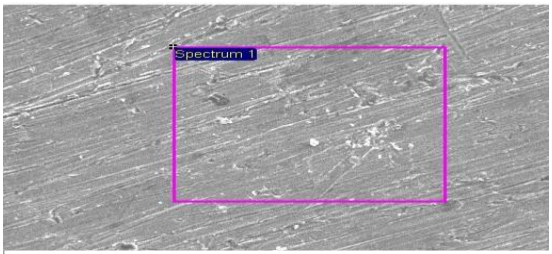




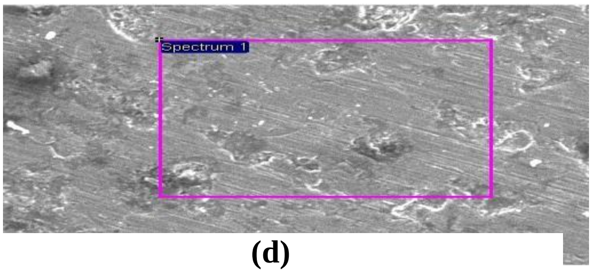
(b)



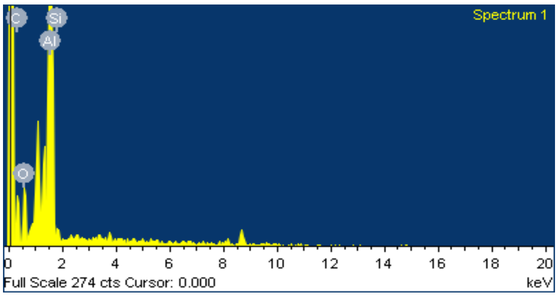




(c)



(d)



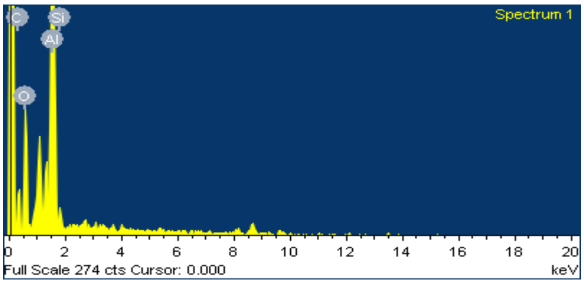


Fig. 7: EDX Analysis of (a) 3% of SiC/ B_4C/ Gr (b) 6% SiC/B_4C/Gr (c) 9% of SiC/ B_4C/ Gr (d) 12% of SiC/B_4C/ Gr

Conclusions

Following Conclusions has been occurred from the present research.

- The matrix and reinforcement wt. % should be in proper proportions for achieving good results.
- The tensile strength and Hardness of the composite are increased with the addition of reinforcement contents and found tensile strength (215Mpa) and hardness (136HB) with the 12% wt of the reinforcement.
- The elongation percentage has been found to a decreasing when the % of reinforcement increases and minimum (1.02%) has been found at the 12% wt of reinforcement.
- Stir casting method is very easy and economically use to fabricate the AMMCs.
- In the SEM and EDX test, the particle distributions were found uniform in 12% weight Reinforcement of composite.

Conflict of interest

The authors have no conflict of interest in the research, authorship, writing and publishing of this manuscript.

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References

[1] Ashok Kumar, M. Muthu Krishnan, A. Felix Sahayaraj, Mohamad Reda A. Refaai, G. Yuvaraj, D. Madhesh and Haiter Lenin Allasi, "Characterization of the Aluminium Matrix Composite Reinforced with Silicon Nitride (AA6061/Si_3N_4) Synthesized by the Stir Casting Route", Hindawi Advances in Materials Science and Engineering, Article ID 8761865 (2022).https://doi.org/10.1155/2022/8761865

[2] RajatYadav, Shashi Prakash Dwivedi, Vijay Kumar Dwivedi,"Effect of Casting Parameters on Tensile Strength of Chrome Containing Leather Waste Reinforced Aluminium Based Composite using RSM", EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol.09, Issue 04, pp1031-1038 (2022).https://doi.org/10.5109/6625716

[3] Rajat Kumar, H. Bhowmick, Dheeraj Gupta, "Progress on the Development of Aluminium Metal Matrix Composite as an Alternative Piston Material- A Review", Journal of Emerging Technologies and Innovative Research (JETIR), (ISSN-2349-5162 (2020).

[4] T.B Rao, "Microstructural, Mechanical, and wear properties characterization and strengthening mechanisms of Al7075/SiCnp composites processed through ultrasonic cavitation assisted stir-casting", Materials Science & Engineering A, S0921-5093(20)31616-6 (2020).

[5] Arun Kumar Sharma, Rakesh Bhandari, Amit Ahewar, Camlia Pinca-Bretotean, "A study of fabrication methods of aluminium based composites focused on stir casting process", Materials Today: Proceedings, 1608–1612 (2020).https://doi.org/10.1016/j.matpr.2020.03.316

[6] Tanuj Kumar Gupta, Rajat Upadhyaya, "Testing and Characterization of Silicon Carbide Reinforced Aluminium Matrix Composites", International Journal of Scientific Engineering and Research (IJSER) ISSN (Online): 2347-3878 (2019).

[7] Shashi Prakash Dwivedi, Manish Maurya, Nagendra Kumar Maurya, Ashish Kumar Srivastava, Satpal Sharma, AmbujSaxena, "Utilization of Ground nut Shell as Reinforcement in Development of Aluminum Based Composite to Reduce Environment Pollution: a review", EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol.07, Issue01, pp15-25 (2020)

[8] Pulkit Garg, Anbesh Jamwal, Devendra kumar, Kishor kumar Sadasivuni, Chaudhery Mustansar Hussain, Pallav Gupta, "Advance research progresses in aluminium matrix composites: manufacturing & applications", J MATER RES TECHNOL, 8(5):4924–4939 (2019).https://doi.org/10.1016/j.jmrt.2019.06.028

[9] P Wahyu Raharjo, Rudy Soenoko, Anindito Purnowidodo, and Agus Choiron, "Characterization of Sodium Bicarbonate Treated Zalacca Fibers as Composite Reinforcements", Evergreen, 6 (1) 29-38 (2019).

[10] S.T Mavhungu, E.T Akinlabi, M.A Onitin, F.M Varachia, "Aluminium metal matrix composites for industrial use: Advances and Trends", international conference on sustainable materials, processing and manufacturing (2017).doi: 10.1016/j.promfg.2016.12.045

[11] Pardeep Sharma, Satpal Sharma, Dinesh Khanduja, "A study on microstructure of aluminium matrix composites", Journal of Asian Ceramic Societies (2015).https://doi.org/10.1016/j.jascer.2015.04.001

[12] Manish Maurya, Nagendra, Kumar Maurya. Vivek Bajpai, "Effect of SiC Reinforced Particle Parameters in the Development of Aluminium Based Metal Matrix Composite", EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 06, Issue 03, pp200-206 (2019).

[13] C.Saravanan, K Subramanian, D B Sivakumar, M Sathyanandhan, R Sankara Narayanan, "Fabrication of Aluminium Metal Matrix Composite –A Review", National Conference on Recent Trends And Developments In Sustainable Green Technologies, Journal of Chemical and Pharmaceutical Sciences, ISSN: 0974-2115 (2015).

[14] Himanshu Kala, K.K.S Mer, Sandeep Kumar, "A Review on Mechanical and Tribological Behaviors of Stir Cast Aluminum Matrix Composites", Procedia Materials Science, 1951 – 1960 (2014).https://doi.org/10.1016/j.mspro.2014.07.229

[15] Pardeep Sharma, Dinesh Khanduja, Satpal Sharma, "Tribological and mechanical behavior of particulate aluminum matrix composites", Journal of Reinforced Plastics and Composites (2014).https://doi.org/10.1177/0731684414556012

[16] Gurpreet Singh and Sanjeev Goyal, Microstructure and Mechanical Behaviour of AA6082- T6/SiC/B4C Based Aluminium Hybrid Composites, Particulate Science and Technology, ISSN: 0272-6351 (Print) 1548-0046, 2016.

[17] Y. Mazaheri, M.Meratian, R.Emadi, A.R. Najarian, "Comparison of microstructural and mechanical properties of Al–TiC, Al–B_4C and Al–TiC–B_4C composites prepared by casting techniques", Materials Science &Engineering A, 560 278–287 (2013).https://doi.org/10.1016/j.msea.2012.09.068

[18] S. Ravindran, Dr. N. Mani, S. Balaji, M. Abhijith, K.Surendaran, "Mechanical Behaviour of Aluminium Hybrid Metal Matrix Composites – A Review", Materials Today: Proceedings, 1020–1033 (2019).

[19] Manish Maurya, Nagendra, Kumar Maurya. Vivek Bajpai, "Effect of SiC Reinforced Particle Parameters in the Development of Aluminium Based Metal Matrix Composite", EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 06, Issue 03, pp200-206 (2019).

[20] Girija Moona, R.S Walia, Rastogi Vikas, Rina Sharma, "Aluminium metal matrix composites: A retrospective investigation", Indian Journal of Pure & Applied Physics, Vol. 56, pp. 164-175 (2018).

[21] G.Anil Kumar, J.Sateesh, Yashas Gowda T G, T.Madhusudhan, "Hybrid Aluminium Metal Matrix Composites and Reinforcement Materials: A Review", International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), ISSN(Online) : 2319-8753, Vol. 5, Issue 4 (2016).

[22] Sandeep Chauhan, Vikas Verma, Ujjwal Prakash, P.C Tiwari, "Analysis of powder metallurgy process parameters for mechanical properties of sintered Fe–Cr–Mo alloy steel", Materials and Manufacturing Processes, ISSN1042-6914 (2016).http://dx.doi.org/10.1080/10426914.2016.1221083

[23] Bhaskar Chandra Kandpal, Jatinder kumar, Hari Singh, "Production Technologies of Metal Matrix Composite: A Review", IJRMET, Vol. 4, Issue 2, ISSN : 2249-5762 (2014).

[24] Kapil Bandil, Himanshu Vashisth, Sourav Kumar, Lokesh Verma1, Anbesh Jamwal , Devendra Kumar, Neera Singh, Kishor Kumar Sadasivuni and Pallav Gupta, Microstructural, mechanical and corrosion behaviour of Al–Si alloy reinforced with SiC metal matrix composite, Journal of Composite Materials 0(0) 1–9, 2019
DOI: 10.1177/0021998319856679

[25] Rajesh Kumar Bhushan, Synthesis and characterization of 7075 Al alloy–SiC composites, International Journal of Structural Integrity ISSN: 1757-9864, Vol. 12 No. 2, pp. 322-339, 2021. https://doi.org/10.1108/IJSI-01-2020-0010

[26] Rajat Kumar, Vijay Kumar Dwivedi, Anas islam, Shasi prakash dwivedi, Analysis of mechanical properties of Al-based metal matrix composite reinforced with ES and RHA, ISSN: 1708-5284, Vol. 18 No. 6, pp. 930-937, 2021. https://doi.org/10.1108/WJE-02-2021-0079

[27] M. Sambathkumar, R. Gukendran, T. Mohanraj, D. K. Karupannasamy, N. Natarajan, David Santosh Christopher, A Systematic Review on the Mechanical, Tribological, and Corrosion Properties of Al 7075 Metal Matrix Composites Fabricated through Stir Casting Process,Advances in Materials Science and Engineering, Volume 2023 | Article ID 5442809 | https://doi.org/10.1155/2023/5442809

[28] S. Senthil Murugan,M. Vigneshkumar,M. John Iruthaya Raj, Sivamani Selvaraju,N. Vinayaka,Srinivasan Murugan,V. Vijayan,and Addisalem Mekonnen, Stir Casting Processing, Mechanical, and Wear Behavior of AA2024 +10 wt. % Flyash +5 wt. % Graphite Hybrid Composite, Advances in Materials Science and Engineering, Volume 2023 | Article ID 9089620. https://doi.org/10.1155/2023/9089620

[29] Tanimu Kogi Ibrahim, Danjuma Saleh Yawas, Bashar Dan-asabe & Adetayo Abdulmumin Adebisi, Taguchi optimization and modelling of stir casting process parameters on the percentage elongation of aluminium, pumice and carbonated coal composite, Scientific reports Article number: 2915 (2023). https://doi.org/10.1038/s41598-023-29839-8