Annales de Chimie - Science des Matériaux
Vol. 43, No. 5, October, 2019, pp. 341-346
Journal homepage: http://iieta.org/journals/acsm

Microstructure and Mechanical Properties of Al 6061/Al_2O_3/Fly-Ash Composite Fabricated Through Stir Casting

Shashi Prakash Dwivedi[1], Ashish Kumar Srivastava[1], Nagendra Kumar Maurya[1], Manish Maurya[2*]

[1] G. L. Bajaj Institute of Technology and Management, Greater Noida, Gautam Buddha Nagar, U.P. 201306, India
[2] Accurate Institute of Management and Technology, Greater Noida, Gautam Buddha Nagar, U.P. 201308, India

Corresponding Author Email: manish.maurya@accurate.in

https://doi.org/10.18280/acsm.430510

Received: 11 August 2019
Accepted: 9 October 2019

Keywords:
hybrid composite, Al_2O_3, fly-ash, tensile strength, hardness, ductility

ABSTRACT

The fly-ash produced in thermal power plants is a major pollutant to the air and soil. This paper designs a new composite material with the fly-ash as the reinforcement. For the composite, the AA 6061 aluminum alloy was taken as the matrix, Al_2O_3 as the primary reinforcement, and fly-ash as the secondary reinforcement. The microstructure and mechanical properties of the proposed composite were measured, and compared with those of previous experiments on AA 6061 alloy. The results show that the proposed composite achieves uniform distribution of Al_2O_3 and fly-ash in AA 6061 alloy; the mechanical characteristics like tensile strength and hardness were improved after adding Al_2O_3 and fly-ash; however, ductility and facture toughness were minimized after the addition. The research findings offer a new way to recycle the fly-ash generated in the thermal power industry.

1. INTRODUCTION

Development of composite material by using industrial waste is one of the most attention-grabbing research areas in manufacturing [1]. There are different types of industrial wastes produced in the environment. Such wastes produce more soil and air pollution [2]. Industrial wastes are also very harmful for human body and the environment [3]. By utilizing the industrial wastes in fabrication of composites, some environment problem can be minimized. Further, clearances of these wastes are also very costly [4].

The development of new composite materials with minimum waste is one of the most remarkable research areas in the present situation [5]. Nowadays, many researchers throughout the world are focusing on the green manufacturing technique [6]. Green manufacturing is the renewal of manufacturing route which provide clean environment condition or give the method so that environment can keep green by reducing the waste material [7].

Reddy et al. [8] developed SiC and Fly-ash reinforced aluminium metal matrix hybrid composites through by stir casting method to evaluate the mechanical characteristics like ultimate tensile strength, hardness and wear. Results depicted that hybrid composite had better mechanical properties than base metal. Kanth et al. [9] investigated the effect of fly ash/SiC particles reinforcement on Al-Zn alloy based composite. Experimental results revealed that addition of Fly-ash results in grain refinement. Owing to reinforcement of Fly-ash hardness and tensile strength of material had improved. Bhushan et al. [10] carried study to optimize the stir casting method parameters for better porosity of 7075 Al alloy/SiC composite. Results concluded that 10 % SiC reinforcement results optimum porosity. Yu et al. [11] have prepared AA 6061-31 % B_4C composite via stir casting process to investigate the mechanical characteristics. Experimental results showed that vacuum stirring was required to successful casting of AA6061/ B_4C composite. B_4C particles were evenly dispersed in the composite. Singh et al. [12] have fabricated LM 24/B_4C composites via stir casting technique to observe the mechanical characteristics i.e. ultimate tensile strength, hardness and impact strength. Results depicted that mechanical properties increased with increase of B_4C particles. Bharath et al. [13] have developed 6061Al-Al_2O_3 MMC's by stir casting process to observe the mechanical and wear property. It was observed that addition of Al_2O_3 results refined grain size in the composite. From previous reported review [14], it was found that B_4C [15], SiC [16-17], and eggshell [18] was reinforced to aluminium alloy to form the composite.

Hanizam et al. [19] optimized the stir casting parameters using Taguchi technique to fabricate A356/MWCNT composite. The uniform dispersal and pull-outs of MWCNT across the grain boundaries was found in the SEM images. Maximum UTS and hardness values of 277 MPa and 106.4 HV was found for specimen containing 0.5 wt. % (Mg and MWCNT) having 600 seconds of mechanical stirring time. Ultimate tensile strength (108.4 %) and hardness (76.3 %) of the composite was enhanced in comparison to casted A356 alloy. Sahu et al. [20] manufactured Al 7075 B_4C /fly ash composite by using stir casting technique. Al 7075/2 wt. % FA/8 wt. % B_4C composite had the micro-hardness of 123.29 HV. 37.2 % improvement in micro hardness was observed. This investigation concluded that the reinforcement of B_4C and Fly-ash content in the Al matrix resulted in enhancement of micro hardness of prepared composite with the increase of B_4C particles in the matrix. Sivanathan et al. [21] investigated the influence of SiC content in Al 6061 alloy. Stir casting technique was used to fabricate the composite. Compression strength, tensile strength and hardness was improved up to 12 %, 25.6 % and 25 % in comparison to aluminium 6061 alloy. Mistry and Gohil [22] evaluated the wear behavior of AA 7075/Si3N4 composite developed through stir casting process. Hardness, tensile strength and flexural strength was improved for the AA 7075/Si3N4 composite. Wear rate of the prepared composite was reduced in compare to AA 7075 alloy.

In the present era the use of composite material is of tremendous use due to enhanced microstructural and mechanical properties. Metal matrix composites are in huge demand due to their light weight, high tensile strength, hardness and less wear resistance in automotive and air craft industries. Generally, Al_2O_3 and B_4C particles are mostly used for reinforcement in aluminum alloy. An attempt is made to use Al_2O_3 and fly ash content as reinforcement to fabricate hybrid metal matrix composites.

Through literature survey, it was found that very few researchers have developed AA 6061 base matrix material composite by using Al_2O_3 as primary reinforcement content and Fly-ash as secondary reinforcement material. Owing to these research gap, AA 6061/Al_2O_3/Fly-ash hybrid metal matrix composite was fabricated. Mechanical properties of hybrid composite were observed to see the effect of Al_2O_3 and Fly-ash addition in the development of hybrid composite material. Heat treatment process was also carried out to observe the effect of heat treatment on mechanical behavior of AA 6061/Al_2O_3/Fly composite.

2. MATERIALS AND METHODS

2.1 Matrix material

In this investigation, AA 6061 material was taken as matrix material. AA 6061 materials are used in the fabrication of wings and fuselages in aircraft structures. It is used in the yacht construction. AA 6061 alloys were also used in fabrication of chassis of the Audi A8. AA 6061 alloy was also very good in wettability with the reinforcement.

2.2 Reinforcement materials

In this research work, Al_2O_3 ceramic particles were used as reinforcement content. Al_2O_3 particles are one of the hardest particles among all the ceramic particles. The secondary reinforcement material is fly ash. Thermal power plant is the good source for collecting fly ash. It contains various hard phases which can improve the mechanical characteristics of composite. Hence, fly ash as the secondary reinforcement content is used in the experiment.

2.3 Preparation of Al6061/Al_2O_3/Fly-ash composite material

AA 6061/Al_2O_3/Fly-ash composite material was fabricated by using stir casting method as shown in Figure 1. AA 6061 matrix material was firstly melted in muffle furnace. Al_2O_3 ceramic particles and Fly-ash were preheated before mixing it in the AA 6061 matrix material. Preheated reinforcement particles were mixed in melted AA 6061 matrix material at temperature 700 °C. Solidified composite was removed for further study. Compositions of prepared composites are shown in Table 1.

Table 1. Composition selection

Sample No.	Compositions	Wt. % of Al_2O_3	Wt. % of Fly-ash
1	AA 6061 + 0 % Al_2O_3+ 0 % Fly-ash	0 %	0 %
2	AA 6061 + 0 % Al_2O_3+15 % Fly-ash	0 %	15 %
3	AA 6061 + 2.5 % Al_2O_3+12.5 % Fly-ash	2.5 %	12.5 %
4	AA 6061+5 % Al_2O_3+10 % Fly-ash	5 %	10 %
5	AA 6061+ 7.5 % Al_2O_3 +7.5 % Fly-ash	7.5 %	7.5 %
6	AA 6061+ 10 % Al_2O_3+5 % Fly-ash	10 %	5 %
7	AA 6061+ 12.5 % Al_2O_3+2.5 % Fly-ash	12.5 %	2.5 %
8	AA 6061+ 15 % Al_2O_3+0 % Fly-ash	15 %	0 %

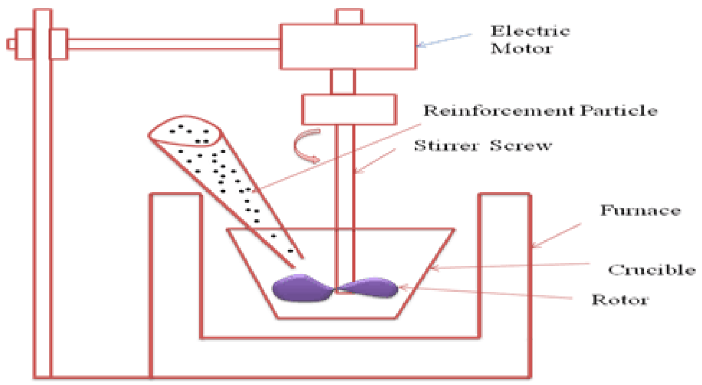

Figure 1. Layout of stir casting method [23]

3. RESULTS AND DISCUSSION

3.1 Microstructure analysis

Figure 2 shows the interfacial reaction layer of fly-ash with aluminium alloy matrix material. Interfacial reaction layer between reinforcement particle and matrix material always play a significant role in enhancing the mechanical properties of composite. If proper chemical reaction takes place between the reinforcement particle and matrix material, proper wettability form between the matrix material and reinforcement particles. Proper wettability between matrix and reinforcement particles reduced the porosity and blow holes inside the composite material after the solidification process [24]. Microstructure image (Figure 2) shows proper interfacial reaction layer between AA6061 matrix material and Fly-ash. This proper interfacial reaction layer may the accountable in improving the mechanical properties of hybrid composite.

Figure 3 illustrated the microstructure image of Al 6061/Al_2O_3/Fly-ash hybrid composite material. Microstructure image shows the presence of Al_2O_3 and Fly-ash in AA6061 matrix material. From the microstructure image, it can be observed that reinforcement particles are fairly distributed in the matrix material.

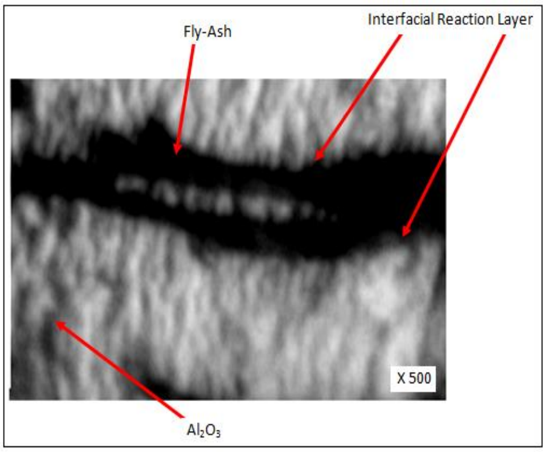

Figure 2. Interfacial reaction layer of fly-ash with matrix material

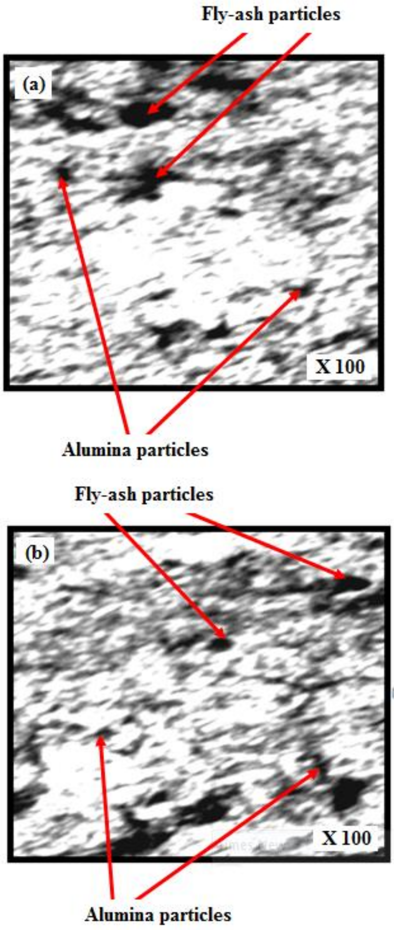

Figure 3. Microstructure of composite material

3.2 Tensile strength examination

Tensile strength of hybrid metal matrix composite was calculated to observe the effect of addition of reinforcement particles. Results concluded that by the addition of Al_2O_3 ceramic content and Fly-ash waste in AA 6061 alloy, tensile strength was improved. Maximum tensile strength was obtained to be 175 MPa for composition AA6061+7.5 % Fly-ash + 7.5 % Al_2O_3 composite after heat treatment. It was observed that after heat treatment process, nearly 66.65 % of tensile strength was enhanced as shown in Figure 4.

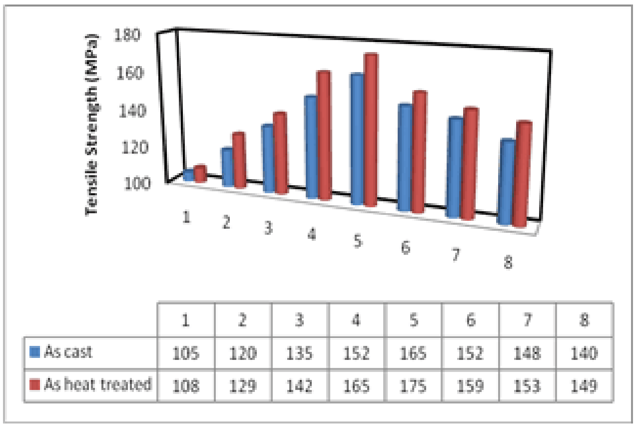

Figure 4. Tensile strength of hybrid metal matrix composite

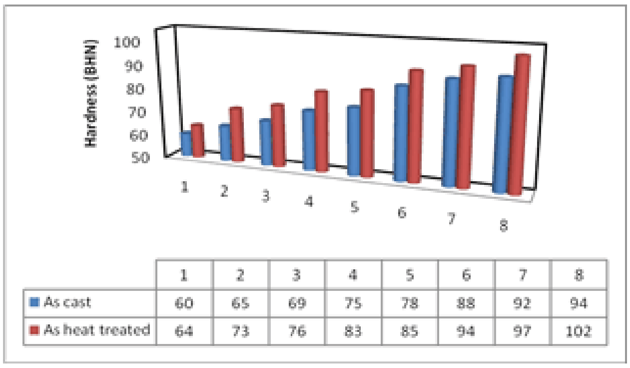

Figure 5. Hardness for hybrid metal matrix composite

3.3 Hardness

Hardness of hybrid metal matrix composite was found to see the influence of reinforcement content in AA 6061 alloy. 94 BHN for was the maximum hardness obtained for AA 6061+0 % Fly-ash + 15 % Al_2O_3 composite. Hardness of composite was further enhanced by heat treatment method. The hardness of heat treated composite for sample 8 was found to be 102 BHN as shown in Figure 5. Hardness of the composite material is always enhanced by the addition of reinforcement particles. Presence of hard phases in the reinforcement particles is responsible in enhancing the hardness. Fly-ash contains SiO_2, Al_2O_3 and Fe_2O_3. These all elements are responsible for enhancing the hardness of composite. It can be observed that hardness was further improved after the heat treatment process. Grain structure refinement may the reason of increased hardness after the heat treatment process. Further, after heat treatment process, the crystal structure consists of atoms that are grouped in a very specific arrangement, called a lattice. In most elements, this order will rearrange itself, depending on conditions like temperature and pressure. This rearrangement, called allotropy or polymorphism, may occur several times, at many different temperatures for a particular metal. In alloys, this rearrangement may cause an element that will not normally dissolve into the base metal to suddenly become soluble, while a reversal of the allotropy will make the elements either partially or completely insoluble.

3.4 Fracture toughness

Fracture toughness of hybrid composite was investigated to evaluate the impact strength of composite. Results showed that fracture toughness was continuously decreased by the addition of reinforcement content in AA6061 alloy. Minimum toughness was found to be 6.5 Joule/m^3, for sample number 8 (AA6061+0% Fly-ash + 15 % Al_2O_3) as shown in Figure 6. Fracture toughness always reduced after the incorporation of hard ceramic particles into the matrix material. Presence of hard phases in fly-ash and Al_2O_3 ceramic particle in matrix material is responsible for reducing the toughness of composite. However, fracture toughness was increased after the heat treatment process. Metallic materials consist of a microstructure of small crystals called "grains" or crystallites. The nature of the grains (i.e. grain size and composition) is one of the most effective factors that can determine the overall mechanical behaviour of the metal. Heat treatment provides an efficient way to manipulate the properties of the metal by controlling the rate of diffusion and the rate of cooling within the microstructure. Due to the above phenomena, fracture toughness of the composite was increased after the heat treatment process.

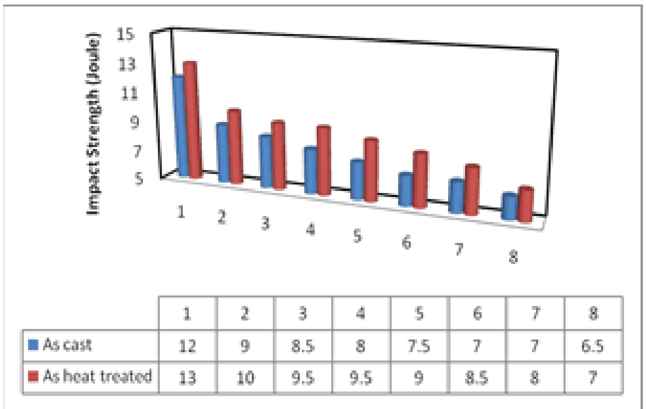

Figure 6. Toughness results of hybrid metal matrix composite

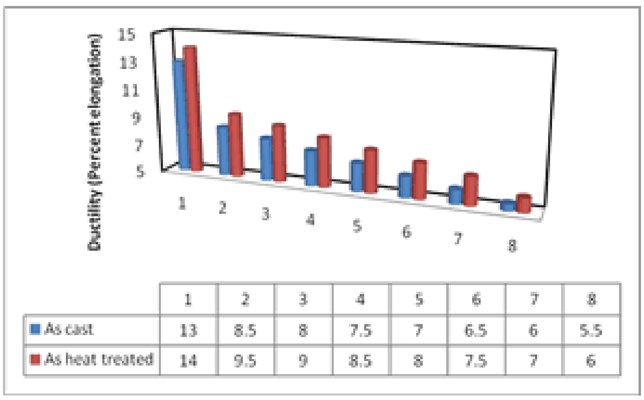

Figure 7. Ductility of hybrid metal matrix composite

3.5 Ductility (percentage elongation)

The percent elongation of hybrid metal matrix composite is shown in Figure 7. Results illustrated that by the reinforcement of Al_2O_3 content and Fly-ash in AA 6061 alloy, percent elongation of hybrid composite material was continuously decreased. However, ductility of the composite reduced after the addition of fly-ash and alumina in matrix material. But, after the heat treatment process, ductility was further improved. Enhancement in the ductility was due to the grain refine structure of the composite.

3.6 Corrosion Behaviour

Corrosion behaviour of the composite material was also observed to identify the fly-ash and alumina particle addition effect on aluminium alloy base matrix material. Corrosion behaviour of composite was observed in 3.5 wt. % NaCl for 72 hours. Weight of each sample before test was kept 9 gm. Maximum tensile strength was found for composition AA 6061+ 7.5 % Al_2O_3 +7.5 % Fly-ash. Hence corrosion behaviour was observed for this sample. Comparative study of composite material weight loss with aluminium alloy is shown in Figure 8. From the study, it can be observed that negligible amount of weight was reduced after the corrosion test of the composite.

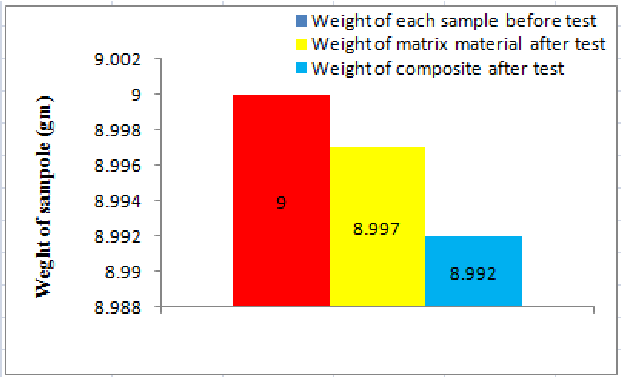

Figure 8. Corrosion behaviour of composite

4. COMPARISON OF RESULTS WITH OTHER PERFORMED EXPERIMENTS

Table 2 illustrates the comparative investigation of the influence of reinforcement content (fly ash/ Al_2O_3) performed by other researchers in AA 6061 alloy. Yashpal et al. [25] prepared AA 6061/fly ash/ Al_2O_3 composite by stir casting method. The maximum hardness was observed for AA 6061/4 % fly ash/ 6 % Al_2O_3 composite. fly ash content had improved the micro hardness of developed composite. Wessley et al. [26] fabricated AA 6061/fly ash/ Al_2O_3 composite by stir casting method to investigate the mechanical properties. Hardness and tensile strength were improved.

In this investigation, an attempt is made to fabricate AA 6061/ fly ash/ Al_2O_3 composite by stir casting method. Mechanical properties like hardness, tensile strength, ductility along with fracture strength of the prepared composite is investigated. It can be concluded that the mechanical properties of the manufactured composite through stir casting technique are consistent with the archival literature. Some significant improvement in tensile strength and hardness of the material are observed in these experiments.

Table 2. Comparison of experimental results with archival literature data

S. No.	Authors'	Composite Fabricated	Properties Investigated
1	Yashpal et al. [21]	AA 6061/Fly ash/ Al_2O_3	Maximum Microhardness=50.3 HV Hardness=89 RHN Density=2.7 g/cm3
2	Wessley et al. [22]	AA 6061/Fly ash/ Al_2O_3	Tensile Strength = 171.54 MPa Hardness = 68.6 HV
3	Present Investigation	AA 6061/Fly ash/ Al_2O_3	Tensile Strength = 175 MPa Hardness = 102 BHN Fracture Toughness = 7 Joule Ductility = 6 % elongation

5. CONCLUSIONS

Through the conducted experiments, the following results can be concluded-

1 Fly-ash is a thermal power plant waste that produces soil and air pollution around thermal power plant industries. It can be effectively utilized in fabrication of the composites.

2 AA 6061 aluminium alloy was used as matrix material in the fabrication of hybrid composite material in which Al_2O_3 was used as a primary reinforcement content and Fly-ash as secondary reinforcement content.

3 Results concluded that addition of Al_2O_3 and Fly-ash in AA 6061 alloy had improved the tensile strength and hardness of composite.

4 94 BHN for was the maximum hardness obtained for AA 6061+0 % Fly-ash + 15 % Al_2O_3 composite. Maximum tensile strength was obtained to be 175 MPa for composition AA6061 + 7.5 % Fly-ash + 7.5 % Al_2O_3 composite after heat treatment.

5 Toughness and ductility reduced by adding the ceramic particles in AA6061 matrix material. Minimum toughness was found to be 6.5 Joule/m^3, for sample number 8 (AA6061+0 % Fly-ash + 15 % Al_2O_3)

DECLARATION OF CONFLICTING INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ACKNOWLEDGEMENT

The author(s) received no financial support for the research, authorship, and/or publication of this article.

REFERENCES

[1] Sharma, P., Khanduja, D., Sharma, S. (2015). Parametric study of dry sliding wear of aluminium metal matrix composites by response surface methodology. Materials Today: Proceedings, 2: 2687-2697. https://doi.org/10.1016/j.matpr.2015.07.234

[2] Rao, R.N., Das, S.D., Mondal, P., Dixit, G., Devi, S.L.T. (2013). Dry sliding wear maps for AA7010 (Al-Zn-Mg-Cu) aluminium matrix composite. Tribology International, 60: 77-82. https://doi.org/10.1016/j.triboint.2012.10.007

[3] Rajmohan, T., Palanikumar, K., Ranganathan, S. (2013). Evaluation of mechanical and wear properties of hybrid aluminium matrix composites. Transactions of Nonferrous Metals Society of China, 23: 2509-2517. https://doi.org/10.1016/S1003-6326(13)62762-4

[4] Baradeswaran, A., Vettivel, S.C., Perumal, A.E., Selvakumar, N., Issac, R.F. (2014). Experimental investigation on mechanical behaviour, modelling and optimization of wear parameters Of B4C and graphite reinforced aluminium hybrid composites. Materials & Design, 63: 620-632. https://doi.org/10.1016/j.matdes.2014.06.054

[5] Alshmri, F., Atkinson, H.V., Hainsworth, S.V., Haidon, C., Lawes, S.D.A. (2014). Dry sliding wear of aluminium-high silicon hypereutectic alloys. Wear, 313(1-2): 106-116. https://doi.org/10.1016/j.wear.2014.02.010

[6] Kumar, N.G.S., Ravindranath, V.M., Shankar, G.S.S. (2014). Mechanical and wear behaviour of aluminium metal matrix hybrid composites. Procedia Materials Science, 5: 908-917. https://doi.org/10.1016/j.mspro.2014.07.378

[7] Ganesh, R., Subbiah, R., Chandrasekaran, K. (2015). Dry sliding wear behavior of powder metallurgy aluminium matrix composite. Materials Today: Proceedings, 2: 1441-1449. https://doi.org/10.1016/j.matpr.2015.07.065

[8] Reddy, B.R., Srinivas, C. (2018). Fabrication and characterization of silicon carbide and fly ash reinforced aluminium metal matrix hybrid composites. Materials Today Proceeding, 5(2): 8374-8381. https://doi.org/10.1016/j.matpr.2017.11.531

[9] Kanth, U.R., Rao, P.S., Krishna, M.G. (2019). Mechanical behaviour of fly ash/SiC particles reinforced Al-Zn alloy-based metal matrix composites abricated by stir casting method. Journal of Materials Research and Technology, 8(1): 737-744. https://doi.org/10.1016/j.jmrt.2018.06.003

[10] Bhushan, R.K., Kumar, S., Das, S. (2010). Effect of machining parameters on surface roughness and tool wear for 7075 Al alloy SiC composite. Int J Adv Manuf Technol, 50: 459-469. https://doi.org/10.1007/s00170-010-2529-2

[11] Li, Y., Li, Q.I.D., Li, D., Liu, W., Shu, G.G. (2016). Fabrication and characterization of stir casting AA 6061-31 % B4C composite. Transactions of Nonferrous Metals Society of China, 26(9): 2304-2312. https://doi.org/10.1016/S1003-6326(16)64322-4

[12] Singh, K., Rana, R.S., Pandey, A. (2017). Fabrication and mechanical properties characterization of aluminium alloy LM24/B4C composites. Materials Today Proceeding, 4(2): 701-708. https://doi.org/10.1016/j.matpr.2017.01.075

[13] Bharath, V., Nagaral, M., Auradi, V., Kori, S.A. (2014). Preparation of 6061Al-Al_2O_3 MMC's by stir casting and evaluation of mechanical and wear properties. Procedia Materials Science, 6: 1658-1667. https://doi.org/10.1016/j.mspro.2014.07.151

[14] Maurya, M., Kumar, S., Bajpai, V. (2019). Assessment of the mechanical properties of aluminium metal matrix composite: A review. Journal of Reinforced Plastics and Composites, 38(6): 267-298. https://doi.org/10.1177/0731684418816379

[15] Maurya, N.K., Maurya, M. (2017). Fabrication of A359 alloy reinforced with B4C particulates & characterization of mechanical properties. International Journal of Advance Research in Science and Engineering, 6: 532-538.

[16] Maurya, N.K., Maurya, M., Srivastava, A.K., Dwivedi, S.P., Kumar, A., Chauhan, S. (2019). Investigation of mechanical properties of Al 6061/SiC composite prepared through stir casting technique. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2019.09.003

[17] Maurya, M., Maurya, N.K., Bajpai, V. (2019). 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, 6(3): 200-206.

[18] Dwivedi, S.P., Maurya, N.K., Maurya, M. (2019). Effect of uncarbonized eggshell weight percentage on mechanical properties of composite material developed by electromagnetic stir casting technique. Revue des Composites et des Matériaux Avancés, 29 (2): 101-107. https://doi.org/10.18280/rcma.290205

[19] Hanizam, H., Salleh, M.K., Omar, M.Z., Sulong, A.B. (2019). Optimisation of mechanical stir casting parameters for fabrication of carbon nanotubes–aluminium alloy composite through Taguchi method. Journal of Materials Research and Technology, 8: 2223-2231. https://doi.org/10.1016/j.jmrt.2019.02.008

[20] Sahu, M.K., Sahu, R.K. (2019). Synthesis, microstructure and hardness of Al 7075/B4C/Fly-ash composite using stir casting method. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2019.09.150

[21] Sivananthan, S., Ravi, K., Samson, C., Samuel, J. (2019). Effect of SiC particles reinforcement on mechanical properties of aluminium 6061 alloy processed using stir casting route. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2019.09.068

[22] Mistry, J.M., Gohil, P.P. (2019). Experimental investigations on wear and friction behaviour of Si3N4p reinforced heat treated aluminium matrix composites produced using electromagnetic stir casting process. Composites Part B: Engineering, 161: 190-204. https://doi.org/10.1016/j.compositesb.2018.10.074

[23] Dwivedi, S.P., Srivastava, S., Kumar, A., Nandana, B. (2017). Microstructure and mechanical behaviour of RHA and B_4C reinforced aluminium alloy hybrid metal matrix composite. Indian Journal of Engineering & Materials Sciences, 24: 133-140.

[24] Alaneme, K.K., Sanusi, K.O. (2015). Microstructural characteristics, mechanical and wear behaviour of aluminium matrix hybrid composites reinforced with alumina, rice husk ash and graphite. Engineering Science and Technology, An International Journal, 18(3): 416-422. https://doi.org/10.1016/j.jestch.2015.02.003

[25] Yashpal, Panwar, N., Gouda, M.M., Kant, S. (2018). Experimental investigation of AA6061-Al_2O_3-fly ash composite produced by using stir casting method. Materials Today: Proceedings, 5(14): 28413-28419. https://doi.org/10.1016/j.matpr.2018.10.127

[26] Wessley, G.J.J., Srinivas, S., Ali, M.D.A. (2019). Preparation and characterization of an aluminium 6061 alloy based metal matrix composite. International Journal of Engineering and Advanced Technology, 8 (3S): 113-116.