RP Current Trends In Engineering and Technology
Vol. 3, No. 1 (January – March 2024) pp. 13–19
e-ISSN: 2583-5491

Cite this article: G. Ramana, Y.S. Supraja, T. Rajashekar, A. Rahul, B. Devender, Y.V.S.S.S.V. Prasada Rao, Experimental analysis of Al6061/SiC/B_4C/Fly-ash metal matrix composite, *RP Cur. Tr. Eng. Tech.* **3** (2024) 13–19.

Original Research Article

Experimental analysis of Al6061/SiC/B_4C/Fly-ash metal matrix composite

Gulda Ramana, Yadavalli Sai Supraja, Tejavath Rajashekar, Adapally Rahul, Banothu Devender*, Y.V.S.S.S.V. Prasada Rao
Department of Mechanical Engineering, Vignana Bharathi Institute of Technology, Hyderabad, India
*Corresponding author, E-mail: devender.banothu@vbithyd.ac.in

ARTICLE HISTORY
Received: 13 Dec. 2023
Revised: 22 Jan. 2024
Accepted: 23 Jan. 2024
Published online: 24 Jan. 2024

KEYWORDS
MMC (Metal Matrix Composite);
Reinforcement;
Mechanical properties;
Micro-structure.

ABSTRACT
Composite materials of Aluminum alloys Al6061 have high strength to weight ratio. High-strength forging alloy Al6061 that can be heat treated. Similar to the Al7075 alloy, but with better toughness and tensile strength, it has a superb balance of toughness and strength. The engineers have studied this metals characteristic. The problems associated with employing aluminum alloys in manufacturing have been resolved by contemporary manufacturing techniques. This led to a great desire for the application of aluminum alloy in all engineering domains. Due to their vital qualities including enhanced specific strength, high temperature and wear resistance, aluminum metal matrix composites are becoming increasingly popular for automotive, aerospace, agricultural farm machinery, defense sector, and many other industrial applications. By adding reinforcements made of Boron Carbide (B_4C), Silicon Carbide (SiC), and Fly-Ash to the Al6061 matrix, the mechanical parameters such as tensile strength, compression strength, and hardness can be improved. Creating four different with varying makeup and performing Tensile test, Hardness test, Bending test and Micro-structure on each specimen.

1. Introduction

It was determined that the stir casting process was used to produce the Al6061 composite with proper particle allocation in the Al matrix composite. When more than one reinforcement is used, the characteristics of that composite will improve, and the particular sort of composite is known as a hybrid composite [1]. It was discovered that the stir-casting procedure is used to strengthen Al6061 with B_4C and HEA (High Entropy Alloys) at various weight percentages. The hardness of hybrid metal matrix composites increased as the weight fraction of B_4C and HEA increased. As the B_4C and HEA content increased, the tensile characteristics declined [2]. The research was conducted on the stir-casting methods effects on the mechanical properties of composites made of Al7075/Al_2O_3/SiC nano-metal matrix. Zn serves as the main alloying element. Additionally, the hardness of the matrix material is increased by the diffusion of nano-SiC/Al_2O_3 fragments. And it demonstrates that increasing the reinforcing weight fraction tends to reduce the percentage of elongation, proving that improving the silicon carbide alumina makes materials more brittle [3]. Analyzed the cutting force and surface roughness of hybrid composites made from AA7075, dependent on their composition. Graphene, Al7075-10% SiC-0.1% B4C, and DLC are all examples of materials with this composition. They found that when it comes to machining aluminum alloy, DLC-Coated Carbide is a superior tool to uncoated carbide. As a result of regulated wear and hardness, it extends the tool life [4].

It was observed that impact of SiC reinforcement on the stir-casting Al6061 mechanical characteristics. They employed the following ingredients: Si(0.6), Mn(0.12), Ti(0.14), Zn(0.22), Cr(0.23), Cu(0.18), Fe(0.36), and Mg(0.93). According to test data, Silicon Carbide reinforcement increases the hardness of aluminum alloy 6061 [5]. It was found that due to its simplicity in handling during the manufacturing process, aluminum is a more common matrix material. Because they may give greater mechanical attributes like strength and hardness than other reinforcing particles, SiC, Al_2O_3, and B_4C are the most frequently used [6]. On investigation, it was discovered that the most promising production techniques for MMCs include stir/squeeze casting, powder metallurgy, and semi-solid. The squeeze pressure, which determines the mechanical qualities in the stir/squeeze casting, is the most important factor [7].

It was noted that the maximum hardness for the maximum hardness for the AA6061 + 0% Fly-Ash + 15% Al_2O_3 composite was 94 BHN. After heat treatment, AA6061 + 7.5% Fly-Ash +7.5% Al_2O_3 composites maximum tensile strength was determined to 175 MPa [8]. It was examined that the wear characteristics of composites made of AA7075 MMC reinforced with CNT and fly-ash. Al = 87-91, Zn = 5.1-6.1, Cr = 0.18-0.28, Cu = 1.2-2, Fe = 0.5, Mg = 2.1 – 2.9, Mn = 0.3, Si = 0.4, and Ti = 0.2. Also noticed that the hardness value rises steadily before falling. This is primarily caused by an increase in MWCNT and Fly-Ash [9]. It was observed that how different reinforcements, including those with varying percentages and sizes, affected the performance of composites made of aluminum and metal. Numerous studies on AMMCs have yielded the following information [10].

It was investigated through how the ratio of reinforcement particles affected the Al6061 alloy composites quality. A common aluminum alloy with many uses is Al6061 alloy. Hybrid Al6061 alloy composites with superior micro-structural characteristics were created using the in-situ method. The mechanical, tribological, and corrosion characteristics of the composite were improved [11]. It was investigated into the successful into the successful fabrication of Al6061 metal matrix composite materials using the stir casting method with the mix of fly-ash and epoxy resin. The strength during wear and fatigue will rise when Al6061, fly-ash, and epoxy resin ratio are combined [12].It was investigated into how machining time decreases and toughness automatically increases as silicon carbide % rises. High heat conductivity, better hardness, improved tensile strength, and good yield strength are the benefits. Microwave, aircraft, and electronic packaging are the three primary industries where the principal applications are used extensively [13].

It was observed that the presence of Al7075, Silicon Carbide, Aluminum carbide (Al_4C_3), ternary alumina boron carbide (Al, BC), Boron Carbide (B_4C) and Silicon (Si) in the hybridized composites was confirmed by XRD, and SEM micrographs showed good dispersion of the reinforced particles. Particle agglomeration increases in parallel with the weight percentage of strengthening. As reinforcement is incrementally applied, the impact strength of hybridized composites gradually declines [14].

It was investigated that the aluminum hybrid composite with a 15% weight fraction of silicon carbide and fly ash using stir casting and compared the results of various mechanical tests such as tensile strength (as-cast Al6061: 17Mpa, AHMMC : 37.5Mpa), Compressive strength (as-cast Al6061: 53KN,AHMMC: 56KN), Hardness (as-cast Al6061: 84 HV, AHMMC: 86 HV) [15].

2. Materials and methods

2.1 Materials

Chemically, aluminum is an element with the symbol Al and atomic number 13. Aluminum has a density that is roughly one third that of steel, which is lower than that of most common metals. When exposed to air, it produces a protective oxide layer on the surface because of its strong affinity for oxygen. Due to its colour and exceptional capacity for light reflection, aluminium has an aesthetic resemblance to silver. It is ductile, non-magnetic and soft.

Considering aluminum since it is a cheap, common material with good mechanical and shiny features. In present industries the Al7000 series is widely used because of its excellent strength and mechanical qualities. However, of all series, the Al7000 series is the most expensive. The Al7000 series raises the material price to a very high level.

The primary goal of the project is to increase the mechanical properties and add reinforcement materials to the Al6000 series in order to give it the strength and properties of the Al7000 series. The Al6000 series can be used to cut costs while maintaining the same level of mechanical qualities. This helps in saving the money in many material applications. Selecting Al6061 from the Al6000 family because it can be heat treated. Utilizing the materials of Al6061, Boron Carbide, Silicon Carbide, and Fly-Ash to create the different composition specimens in Table 1.

Table 1: Chemical composition of AA6061

Elements	Mg	Si	Fe	Cu	Cr	Zn	Al
Composition	0.9	0.7	0.6	0.3	0.25	0.1	Balance

Table 2: Composition of reinforcements

No of specimens	SiC	B_4C	Fly-Ash
Specimen 1	4%	-	1%
Specimen 2	-	4%	1%
Specimen 3	3%	3%	-
Specimen 4	3%	3%	1%

Table 3: Tested results of the composites

Sample details	Tensile strength (MPa)	Yield strength (MPa)	Elon-gation (%)
Al6061+4%Sic+1%Flyash	155.58	119.58	6.77
Al6061+4%B_4C+1%Flyash	121.91	95.72	2.74
Al6061+3%Sic+3%B_4C	155.55	94.73	5.26
Al6061+3%Sic+3%B_4C +1%Flyash	129.61	107.41	5.40

Table 4: Hardness test results

Sample ID	1^{st} value	2^{nd} value	3^{rd} value	Avg. value
Al6061+4%Sic +1%Flyash	53.1	53.8	53.6	53.5
Al6061+4%B_4C +1%Flyash	58.2	58.5	57.9	58.2
Al6061+3%Sic +3%B_4C	56.2	57.1	56.8	56.7
Al6061+3%Sic 3%B_4C+1%Flyash	55.2	55.4	54.9	55.1

2.2 Methods

Stir Casting: The easiest, most convenient, and most widely used technique is stir casting, also referred to as the "vortex technique". Reinforcing phases (ceramic particles, short fibers,etc.) are introduced into the molten during this process by mechanical stirring. To obtain better reinforcement distribution, many writers advised adding reinforcement in the form of particulate up to 30% by weight to molten alloy. In order to achieve uniformity during the solidification of the manufactured composite, reinforcement is aggressively introduced to the molten stage of aluminum and is dependent on the following criteria.

- ❖ Time and stirring speed.
- ❖ Stirring blade angle.
- ❖ Reinforcement size, percentage, its relative density.
- ❖ Pouring temperature and solidification rate.

Stir casting was used in the liquid metallurgical process to create aluminum 6061 MMC (Table 1 and 2). Utilizing an electric induction furnace that could achieve a temperature of 500°C, raw materials were added in order to produce liquid metal. When the molten aluminum reaches the liquid stage, it is added to the heated Silicon carbide reinforcement's in a separate chamber. Keep the process parameters constant throughout stirring, such as the melting temperature of 820°C, The stirring duration of 10minutes, and the stirring speed of 400 rpm. Followed the above process to pour into the hot die to produce casting, by using stir casting method (Figure 1).

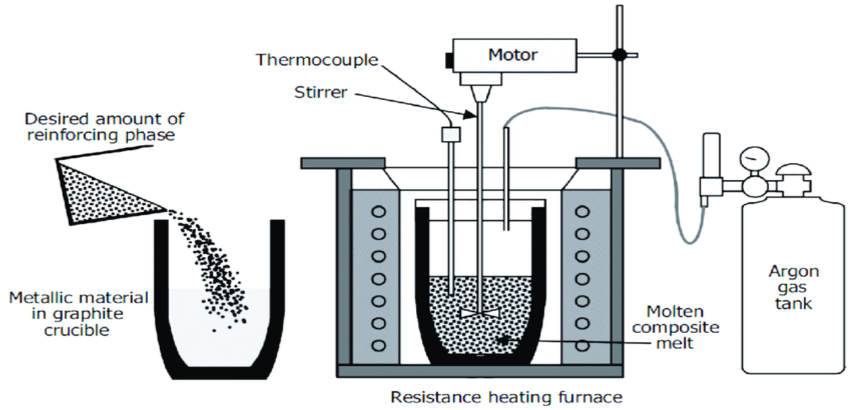


Figure 1: Casting setup

2.3 Components

- ❖ Induction Furnace.
- ❖ Crucible.
- ❖ Rotor.
- ❖ Casting die.

2.3.1 Induction furnace

A metal is heated by induction in an electrical furnace called an induction furnace shown in (Figures 2). From less than one kilogram to one hundred tones, induction furnace capacity is available. Iron, Steel, Copper, Aluminum, and precious metals are all melted in induction furnaces. Unlike electric arc furnaces and furnaces, induction furnaces don't need an arc or combustion. As a consequence, the temperature of the charge (the substance heated in the furnace, not to be confused with electrical charge) is kept at a level that will not cause it to melt, which can help to preserve precious alloying components. The casting process in this procedure uses a medium frequency induction furnace. By using the appropriate frequency, melting of the material of the material is accomplished in this process.

Figure 2: Induction furnace setup

2.3.2 Crucible

Crucibles are made of graphite material as shown in (Figure 3). It can hold up to 10kg at most. It can endure temperatures as high as 3000°C.In the furnace crucible, the foundation material for Al6061 is kept in a fundamental composition. A temperature of 700°C is needed at most. For the substance to melt. The powders will then be added to the liquid substance. The stirring procedure will then begin. This stirring is 600Hz frequency-based stirring. About 1500-3000rpm are used for stirring in this operation.

Figure 3: Crucible setup

2.3.4 Casting die

After melting, the material is poured into a casting die to get the required form shown in (Figure 4). The casted samples are prepared in this process with specified composition.

Figure 4: Die casting setup

Figure 5: Casted samples

2.4 Characterizations

2.4.1 Tensile test

Tensile testing, commonly referred to as tension testing (Figure 7), is a crucial engineering and materials science test in which a sample is put under controlled tension until it fails. Ultimate tensile strength, breaking strength, maximum elongation, and decrease in area are characteristics that may be directly determined by a tensile test. Young's modulus, Poisson's ratio, Yield strength, and features of strain hardening may all be calculated from these observations. To determine the mechanical properties of isotropic materials, uniaxial tensile testing is the method most frequently utilized. Some materials are tested using biaxial tensile methods.

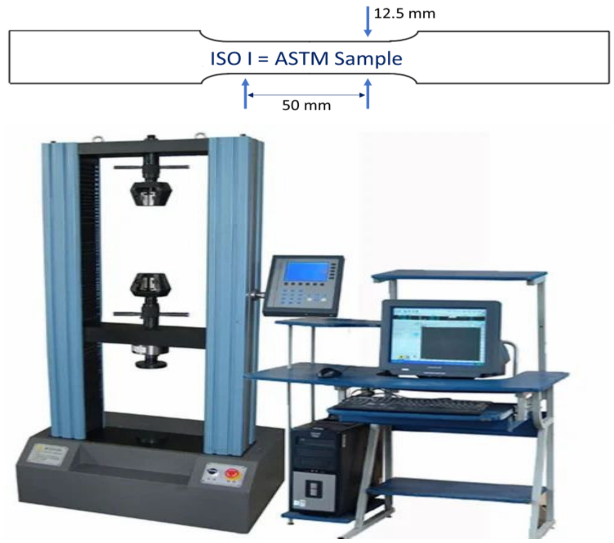


Figure 6: ASTM sample image

Figure 7: Specimen preparation as per ASTM standard image

2.4.2 Hardness test

Al6061 is a kind of aluminum alloy that is often used in several industrial applications. Numerous testing techniques, like as the Brinell, Rockwell, Vickers, and Knoop hardness tests, can be used to determine the alloy's hardness (Figure 6).

The Vickers Hardness test is comparable to the Rockwell test; however, it utilizes a square based diamond pyramid indenter. Based on the force applied and the indentation's surface area, the indentation's size is measured, and the hardness value is calculated.

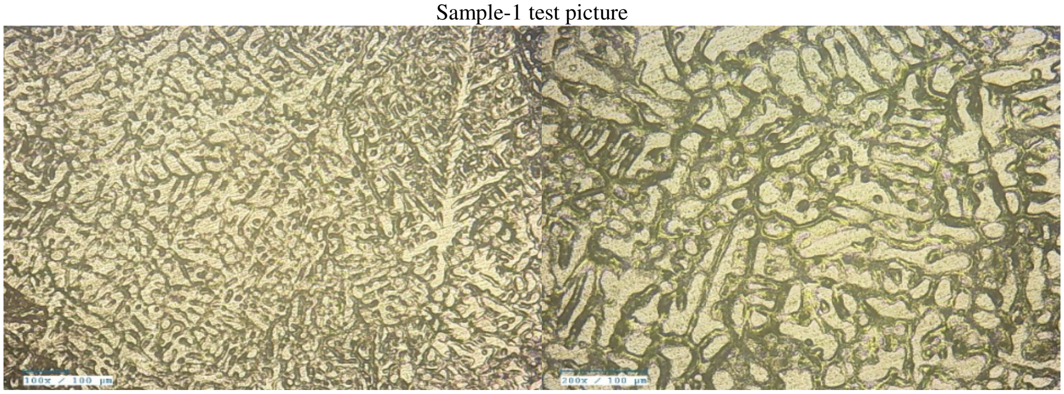
2.4.3 Bending test

Bending tests are often carried out to assess the ductility or resistance to fracture of that material (Figure 6). They deform the test material at the midway, producing a concave surface or a bend to develop without the occurrence of fracture. As opposed to a flexure test, the objective here is to deform the sample into a certain shape rather than load the material until it fails. According to the standard in regard to which the test is conducted, the test sample is loaded to a produce a concave surface with a predetermined radius of curvature at the midway. As common as tensile testing, compression tests, and fatigue tests are bending tests.

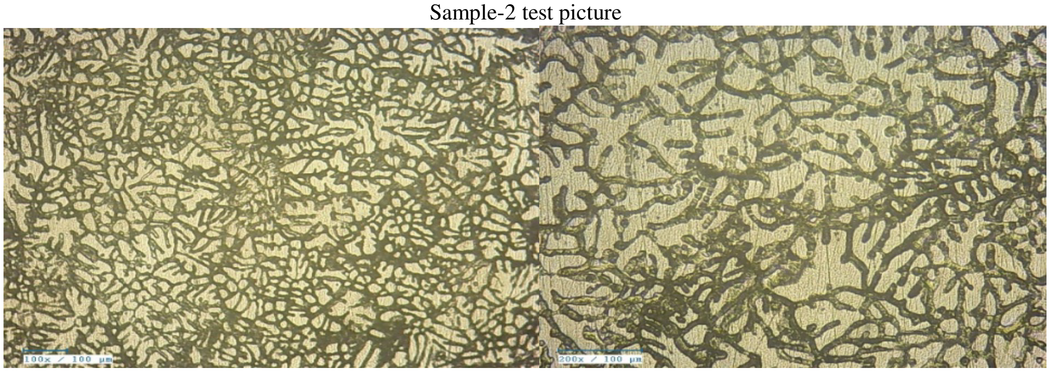
2.4.4 Micro structure

In order to magnify characteristics of the material under inspection, optical or scanning electron microscopes are typically used for microstructural examination. These characteristics quantity and size can be calculated and compared to acceptance standards (Figure 8). In order to identify the kind of material in issue and ascertain if the material underwent the appropriate processing methods, these studies are frequently utilized in failure analysis.

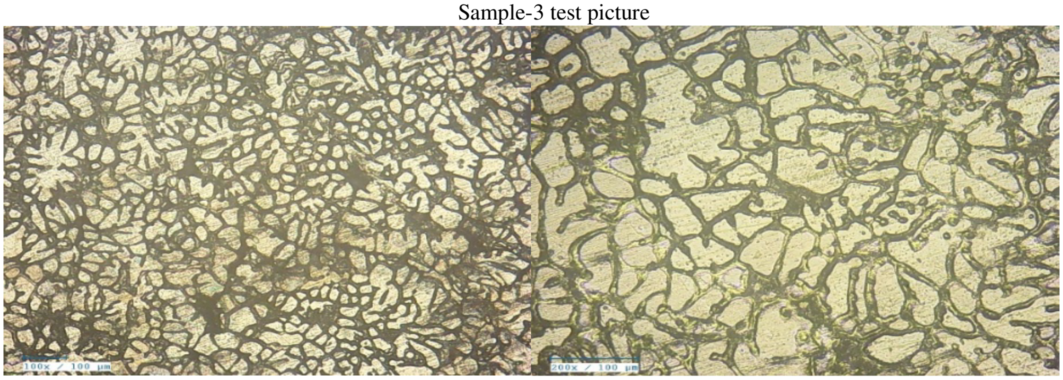
Sample-1 test picture



Sample-2 test picture



Sample-3 test picture



Sample-4 test picture

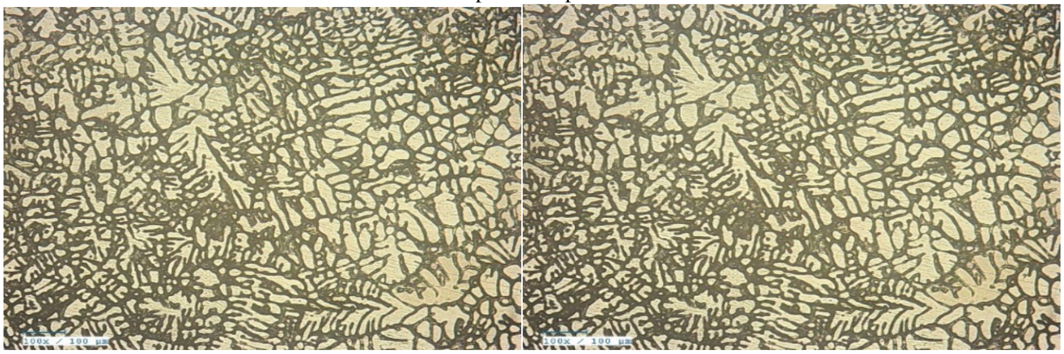


Figure 8: Micro structure images of different specimens.

3. Results and discussion

Analysing the qualities of AA6061 under various circumstances is a part of mechanical testing. This may be accomplished using many tesrt methods, including microstructure analysis, hardness testing, and tensile testing.

In uniaxial tensile testing, an AA6061 sample is put under tension until it breaks. The strength, ductility, and toughness of the material may be determined by this test

Testing for hardness determines how resistant a substance is to penetration or indentation. This test can reveal the strength and hardness of the material.

Brittle materials are typically difficult to test in uniaxial stress due to cracking in thr grips, hence the bending test is utilised to assess the tensile strength of these materials. Most frequently used bending tests include cantilver.

Analysing a material's microstructure entails looking at its tiny composition. This can reveal details on the material's grain size, shape, and orientation, all of which can have an impact on its mechanical properties. In conclusion, these mechanical tests can offer useful data on the characteristics of AA6061, which is crucial for decinding whether it is suitable for different applications.

4. Conclusions

In conclusion, the project on the impact of multiple reinforced particles on metal matrix composites based on aluminum alloys sought to understand how the inclusion of multiple reinforced particles affected the composite's mechanical and microstructural properties. To assess the mechanical properties and microstructure of the composite samples, tensile testing, hardness testing, and microstructural analysis were carried out. The outcomes demonstrated that adding numerous reinforced particles increased the tensile strength and hardness while marginally reducing ductility. Microstructure study revealed that adding reinforced particles caused the particles to be distributed evenly and finely throughout the matrix, which enhanced the mechanical properties. In conclusion, the experiment showed that numerous reinforced particles can enhance the mechanical and microstructural properties of aluminum alloy based metal matrix composites, while the inclusion of silicon carbide boosts the tensile strength and hardness, respectively. The outcomes of this investigation may be helpful in creation of novel composite materials for a variety of engineering applications.

Future scope of the project: There are various potential areas for further research in the project on the impact of multiple reinforced on metal matrix composites based on aluminum alloy. The current study investigates the impact of different reinforced particles contents on metal matrix composites based on aluminum alloys. However it can be pushed even further to look into how different reinforced particle contents affect the mechanical characteristics of the composites. In order to get improved mechanical qualities, this can assist in determining the ideal reinforced particle content.

Fracture analysis: To investigate the fracture behaviours of the composites, more research of the composites, more research might be done in addition to tensile testing. Examining how reinforced particle content and type affect the composites crack propogation and fracture toughness is one possible aspect of this.

Effect of different types of reinforced particles: In the ongoing project, the impact of many reinforced particles on composites is investigated. Additional research can look into how various reinforced particles types affect the mechanical characteristics of the composites. Investigating how particle size, shape, and distribution affect the properties of the composites can be a part of this.

Process optimization: Future research can be concentrate on refining the process variables used to create composites. By doing so, it may be possible to produce composites at a lower cost and with improved mechanical qualities. There are several areas where additional research can be done to better understand the properties and performance of the composites, and the project on the impact of multiple reinforced particles on metal matrix composites based on aluminum alloy has a lot of potential for future research.

References

[1] S. Verma, P. Sudhakar Rao, Study on mechanical behaviour of aluminum alloy 6061 based composite a review, *Int. J. Tech. Innov. Mod. Eng. Sci.* **15** (2018) 16-20.

[2] M. Rishi, S. Raju Chv, L.G. Keni, N.H. Padmaraj, K.N. Chethan, Mechanical characterization of aluminum 6061 with B_4C and high entropy alloys, *Int. J. Mech. Prod. Eng. Res. Dev*. **9** (2019) 527-538.

[3] S. Suresh, G. Harinath Gowd, M.L.S. Deva Kumar, Mechanical properties of AA7075/Al_2O_3/SiC nano-metals matrix composites by stir-casting method, *J. Inst. Eng. India Ser. D* **100** (2019) 43-53.

[4] J.P. Ajithkumar, M. Anthony Xavior, Cutting force and surface roughness analysis during turning of Al7075 based hybrid composites, *Procedia Manufacturing* **30** (2019) 180-

187.
[5] S. Sivananthan, K. Ravi, C. Samson Jerold Samuel, Effect of SiC particles reinforcement on mechanical properties of aluminum 6061 alloy processed using stir casting route, *Mater Today Proc*. **21** (2019) 968-970.
[6] R. Arunachalam, P.K. Krishnan, R. Muraliraja, A review on the production of metal matrix composites through stir casting furnace design, properties, challenges, and research opportunities, *J. Manuf. Proc*. **12** (2019) 213-245.
[7] P.K. Krishnan., S. Piya, M. Al-Maharbi, Processing, properties and microstructure of recycled aluminum alloy composites produced through an optimized stir and squeeze casting process, *J. Manuf. Proc*. **59** (2020) 287-301.
[8] S.P. Dwivedi, P. Sharma, A. Saxena, Utilization of waste spent alumina catalyst and agro-waste rice husk ash as reinforcement materials with scrap aluminium alloy wheel matrix, *Proc IMechE, Part J* 234 (2020) 543–552.
[9] M. Sanju, M. Saravanam, G. Krishna, S. Kumaran, An investigation of wear behaviour on AA7075 MMC reinforced with CNT and fly ash composites, *Mater Today Proc*. **22** (2020) 2460-2468.
[10] S.K. Reddy, M. Kannan, R. Karthikeyan, S. Prashanth, B. Rohith Reddy, A review on mechanical and thermal properties of aluminum metal matrix composites, *E3S Web. Conf.* **184** (2020) 01033.
[11] S.U. Khan, D. Wanwu, Q.Ullah Khan, S. Khan, A. Alam, A. Ullah, H. Ullah, An analysis of in situ synthesized Al6061 alloy metal matrix composites, *Eur. J. Mater. Sci. Eng*. **6** (2021) 220-233.
[12] R. Prathipa, C. Sivakumar, B. Shanmugasundaram, Experimental investigation of aluminum (Al6061) alloy with fly ash metal matrix composite material, *Annals Rom. Soc. Cell Biol*. **25** (2021) 270-288.
[13] A. Natarajan, A. Ali Mohamed Hussain, K. Jaya Kumar, N. Vasu, B. Silambarasan, Experimental investigation of aluminium silicon carbide metal matrix composites, *Int. J. Adv. Res. Sci. Commun. Technol*. **3** (2021) 2581-9429.
[14] M.A. Hassab Alla Mahoud, P. Satishkumar, Y. Srinivasa Rao,C. Rohinikumar, R.Y. Capangpangan, C. Arnold, A. Mahesh Gopal, A. Firos Murthi, C. Saravana, Investigation of mechanical behaviour and microstructure analysis of AA7075/SiC/B_4C-based aluminium hybrid composites, *Adv. Mater Sci. Eng*. **2022** (2022) 2411848.
[15] R. Lubin Raj, G. Bharathiraja, Novel investigation on tensile strength, compressive strength, hardness, corrosion resistance of Al6061 hybrid composite with 15% weight fraction of silicon carbide and fly ash and comparing the outputs with as-cast aluminium 6061, *J. Pharm. Neg. Res*. **13** (2022) 555-567.
[16] N. Panwar, A. Chauhan, Fabrication methods of particulate reinforced aluminium metal matrix composite - A review, *Mater. Today Proc*. **5** (2018) 5933–5939.
[17] B. Ravi, B.B. BaluNaik, J. Udaya Prakash, Characterization of aluminium matrix composites (AA6061/B_4C) fabricated by stir casting technique, *Mater. Today Proc*. **2** (2015) 2984–2990.
[18] M.T. Sijo, K.R. Jayadevan, Analysis of stir cast aluminium silicon carbide metal matrix composite: A comprehensive review, *Procedia Technol*. **24** (2016) 379–385.
[19] R. Singh, R.N. Rai, Characterization of B_4C-composite-reinforced aluminum alloy composites, *AIP Conf. Proc*. **1943** (2018).
[20] A.M. Rajesh, M. Kaleemulla, Experimental investigations o n mechanical behavior of aluminium metal matrixcomposite s, *IOP Conf. Ser. Mater. Sci. Eng*. **149** (2016) 012121.