Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Study on the mechanical behaviour of metal matrix composites (MMC)

S. Venugopal, Sanjeevi Baskar, Pulipaka Neel Fordham Samuel *

Department of Automobile Engineering, Vels Institute of Science Technology and Advanced Studies (VISTAS), Chennai, India

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
MMC
Alloy
Mechanical properties
Aluminium matrix composite
Al_2O_3

ABSTRACT

Combining two or more different base metals to create Metal Matrix Composites (MMC) results in the creation of new metals. Compared to their underlying material, composites offer superior characteristics. In today's industrial sectors, composites are notably important in the automobile sector. In order to create a novel composite using the stir casting process at standard ambient temperature, this work describes the reinforcing of the aluminium alloy with silicon carbide and copper in various ratios. Materials having metals as the base and separate, usually ceramic phases added as reinforcements to improve the characteristics are known as metal matrix composites. Whiskers and particles are examples of possible reinforcements. By changing the type of ingredients and their volume percent, the properties of metal matrix composites can be adjusted. They provide a superior mix of qualities that no monolithic material currently in use can match, and as a result, the aerospace and automotive industries are using them more frequently. MMCs' main advantage over other materials is their increased strength and hardness per unit weight. In this study, the tensile strength, hardness, and flexural strength of the composite were assessed. Sample 2 was discovered to have a maximum tensile strength of 175 MPa and a hardness of 71. The outcome demonstrates that the hybrid composite has superior mechanical characteristics.
Copyright © 2023 Elsevier Ltd. All rights reserved.
Selection and peer-review under responsibility of the scientific committee of the Second International Conference on Advancements in Materials Science and Technology.

1. Introduction

Due to the presence of micro-sized reinforcement particles in the matrix, metal matrix composites (MMCs) are the most promising materials for achieving enhanced mechanical properties such as hardness, Young's modulus, yield strength, and ultimate tensile strength. These enhanced mechanical properties can be achieved by using MMCs. Aluminum matrix composites, also known as AMCs, can be used in a variety of applications across a variety of industries, including the automotive, military, aerospace, and power industries. In order to improve the properties of the 6061-Al alloy, a variety of materials, such as SIC, Al_2O_3, B_4C, TIB2, ZrO_2, and SiO_2, are used as reinforcement. Graphene is also one of these materials [1]. Pistons, cylinder heads, connecting rods, and other components that heavily rely on tribological properties are increasingly being manufactured out of Al_2O_3or SIC particle-reinforced aluminium alloy matrix composites in the aerospace and automotive industries.

Hardness, the amount of stress that is applied, and material composition are all factors that can influence the contact resistance and wear behaviour of conducting contact surfaces [2]. In this study, the material and mechanical properties of functionally graded metal matrix composites (MMCs) made from conducting alloys, more specifically copper/tungsten, copper/tungsten-carbide, and bronze/tungsten-carbide, are investigated. These conducting alloys include copper-tungsten, copper-tungsten-carbide, and bronze-tungsten-carbide [3]. Tungsten and, more specifically, tungsten-carbide reinforcing particles are excellent choices for this application due to their exceptionally high hardness and the wear resistance that comes along with it. It is provided that an overview of the MMC production techniques, along with any associated tradeoffs, can be found in [4]. It presents the findings from measurements of quality, including electrical resistivity, hardness, and density. The volume proportion of constituents within the MMCs and the reinforcing particle distribution were measured using optical microscopy. The outcomes of the microscopy study clarify the differences in properties as a function of casting location. As an illustration of how material properties can be calculated as a function of the particle volume fraction, the rule of mixtures was utilised in this discussion. When compared to the properties

* Corresponding author.
E-mail addresses: venugopal.se@velsuniv.ac.in (S. Venugopal), samuelpulipaka@hotmail.com (P.N.F. Samuel).

https://doi.org/10.1016/j.matpr.2023.01.208
2214-7853/Copyright © 2023 Elsevier Ltd. All rights reserved.
Selection and peer-review under responsibility of the scientific committee of the Second International Conference on Advancements in Materials Science and Technology.

Please cite this article as: S. Venugopal, S. Baskar and Pulipaka Neel Fordham Samuel, Study on the mechanical behaviour of metal matrix composites (MMC), Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2023.01.208

of other conducting alloys, the material properties of MMCs are found to be superior [5]. It was discovered that the base material's conductivity decreased only slightly, whereas the base material's hardness increased significantly [6].

The method of processing that is being employed has a significant impact on the mechanical characteristics of MMCs. By using science-based modelling techniques to enhance the processing process, significant gains may be made. A variety of methods have been used to create composites, including squeeze casting, melt processes, and powder metallurgy [7]. With its capacity to produce more homogeneous dispersions, powder metallurgy seems to be a preferred method. Hot extrusion is commonly used as a post-treatment to benefit from applying compressive pressures and high temperatures at the same time [8].

Despite the fact that powder metallurgy creates MMCs with greater mechanical characteristics, liquid-state processing has certain significant benefits. One of them is improved matrix-particle bonding, as well as easier control over the matrix structure, simplicity, low processing costs, a close-to-net form, and a wide variety of materials. MMCs can be manufactured in a liquid state using two different approaches [9], and the approach that is used is determined by the temperature at which the particle is added to the melt. In both of these processes, the introduction of reinforcing particles is accomplished through the use of a vortex. During the melt stirring process, the particles are incorporated at temperatures that are higher than the liquid temperatures of the molten alloy. On the other hand, during the stir casting method, the particles are important when the alloy is at its semi-solid slurry temperature [10]. However, there are two significant problems with the melting process that must be addressed. The ceramic particles, which sink or float depending on how dense the liquid metal is in comparison to their density, are typically not moistened by the matrix of liquid metal, which is composed of liquid metal. The degree to which a liquid is able to spread over a solid surface is an indication of how closely a liquid and solid are in contact with one another. As a direct consequence of this, the composite possesses poor mechanical properties, a high degree of porosity, and a poor dispersion of ceramic particles [11]. The task of cast synthesis presented here is difficult. The reinforcement particles are able to simply float on the surface of the molten matrix due to surface tension, a large surface area, high interfacial energy, and the presence of an oxide coating on the melt surface. This is because MMC has low wettability. To some degree, wettability can be improved by employing a number of different methods, such as mechanical stirring and preheating the particles in order to remove gases that have deposited on their surface. Reinforcing particles can become unevenly distributed in the molten matrix, which is another problem [12]. As a result of the disparity in density between the matrix and the reinforcement, these particles have a propensity to float or settle in the molten matrix, which leads to the agglomeration and clustering of the particles [13]. The improvement in distribution can be achieved by injecting the particles with an inert carrier gas. The researchers developed a method for the production of Al-MMC that takes into account the incorporation and distribution of reinforcement particles throughout the molten matrix [14]. With its unique ability to develop materials that provide desired qualities, aluminium alloy materials were discovered to be the ideal choice.

Metal matrix composites (MMCs) made of aluminium alloy are becoming more and more popular in the automotive, industrial, and aerospace industries due to their low density, high strength, and excellent structural stiffness. Al6061-SiC and Al6061-SiC/Graphite hybrid composites mechanical characteristics are prepared and compared in the current study. Utilizing the stir casting process, the reinforcement was added in increments of 5 wt%, ranging from 5 to 15 % for the composites [15]. Microstructural analyses and density measurements were used to describe the produced composites, and the mechanical characteristics were assessed in accordance with standards. The composites' microphotographs showed that the distribution of the particles was generally uniform with just a little clumping [16]. In every composite, it was discovered that the experimental densities were lower than the predicted densities. The distributed graphite and silicon carbide in the Al6061 alloy helped to increase the composites' tensile strength [17]. The reinforcement particles were distributed uniformly and without voids in the matrix, according to the samples scanning electron micrographs [18].

2. Experimental work

The cast aluminium alloy 6061 with added graphene particles served as test specimens, and the resultant alloys were put to the test using a Rockwell hardness tester. The tensile and compression tests were done to see how the different ways these alloys were made affected their mechanical properties [19]. The mechanical properties of the aluminium alloy 606 are shown in Table 1.

2.1. Stir casting

It is the most popular casting technique. Melting and casting are combined in the technique known as stir casting. Mixing a dispersed phase into a molten metal matrix is the first step in the stir-casting process, which is a technique for producing composite materials that takes place in a liquid state [20]. Following this step, the liquid composite material is cast using conventional casting techniques. Stir casting uses raw materials effectively while being easy and affordable [21]. The procedure produces a cast product with the highest mechanical qualities possible. In this casting technique, the base metal is first heated in a furnace to melt it. The base metal is combined with the substance to be reinforced while it is still molten. Now that the mixture has been well stirred [22].

2.2. Stir casting method

It is a combination of melting and casting processes.

- To make the sample rods for stir casting, a cavity made out of sand must be used.
- Using the right pattern in the tightly packed sand, the needed mould cavity, which is a cylinder of the right size, is made.
- Melted base metal and particles to be strengthened are poured into the sand mold's space.
- The pouring temperature of the molten metal is around 650–750°Celsius.
- A poured, molten mixture is allowed to solidify within a few seconds.
- The solidified metal is then taken out of the mould and put into the air.
- Finally, the fabricated samples are ready for the next cycle of tests.

Table 1
Mechanical properties of the aluminium alloy 606.

Property	Aluminium alloy 6061
Tensile strength	149.76 (MPa)
Compression strength	296.4 (MPa)
Hardness	45 BHN
Density	2.7 g/cm^3

2.3. Stir casting procedure

It is a combination of melting, stirring, and casting. The process of stir casting consists of various sequences of operations. These operations are carried out in the order in which the stir casting is completed [23]. The order of the sequence is given below.

- Melting
- Stirring
- Pouring
- Solidification
- Removal of samples

2.4. Melting

The 6061 aluminium bar is broken into two halves. This is done for the convenience of preheating. The two halves of the aluminium bar are put into the furnac [24]. The furnace is used for this melting process. After the melting temperature of the metal is reached, the metal starts to melt in the furnace. The melting temperature of aluminium is 650 °C.

2.5. Stirring

The aluminium 6061 bar is in the molten state. The next step is to prepare various samples of different compositions of graphene powder. The two different composition samples that have to be fabricated are aluminium with 3 % graphene and aluminium with 6 % graphene. For fabricating different samples, two different weight percentages of graphene are prepared. For fabricating the samples, Al 6061 + 3 % graphene and Al 6061 + 6 % graphene are prepared. In the case of a graphene sample, the weight of the aluminium is around 125 g.

2.6. Pouring

The molten metal is poured into the cavity created in the mold. The mould cavity contains the required shape into which the molten metal is poured. The molten metal is taken directly from the furnace [25]. For producing the graphene-reinforced samples, molten metal is added to the graphene particles according to the weight percent needed for testing after the samples are fabricated. The pouring temperature ranges between 600 and 650 °C. The effective pouring ensures defect-free samples and porosity-free samples. Pouring is the primary sequence in the stir casting process because sample fabrication is primarily done through pouring [26]. The effective pouring ensures defect-free samples and porosity-free samples. When the cavity for pouring the metal is filled to the correct level, the pouring should be stopped to avoid any extended parts or chipping as a consequence of extended parts.

3. Solidification

Solidification is the final process in the stir casting method. After pouring the molten metal mixture into the mould cavity, it is allowed to solidify for a set amount of time [27]. During the solidification process, the metal is solidified. The time required for the poured molten metal mixture to solidify depends on the reinforcement materials [28]. Normally, the time required for the solidification is about30 s [29] (see Fig. 1–5).

The rate of solidification is a very important parameter in the solidification process. Solidification plays an important role in analysing the properties of the fabricated metal matrix composite of graphene-reinforced aluminium [30]. The time required for the poured molten metal mixture to solidify depends on the reinforcement materials. Normally, the time required for the solidification is about 30 s. In the solidification process, the rate of solidification is

Fig. 1. Molten metal mould flask during solidification.

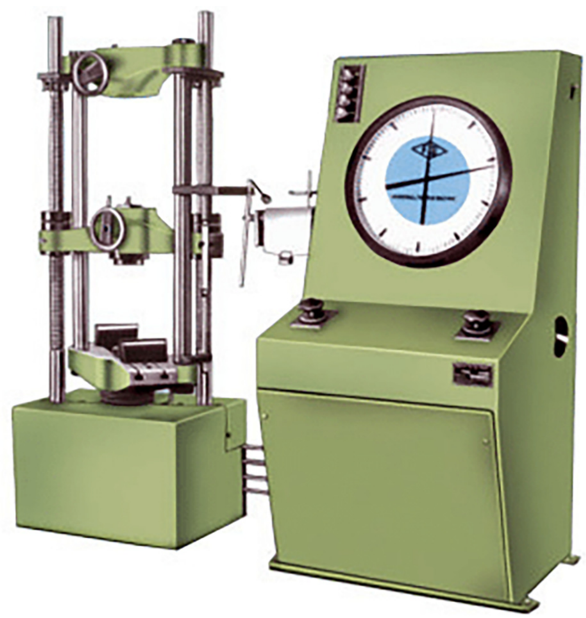

Fig. 2. UTM setup.

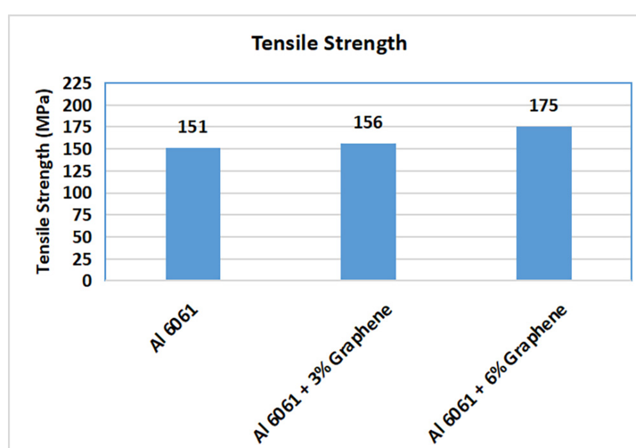

Fig. 3. Comparison of tensile strength.

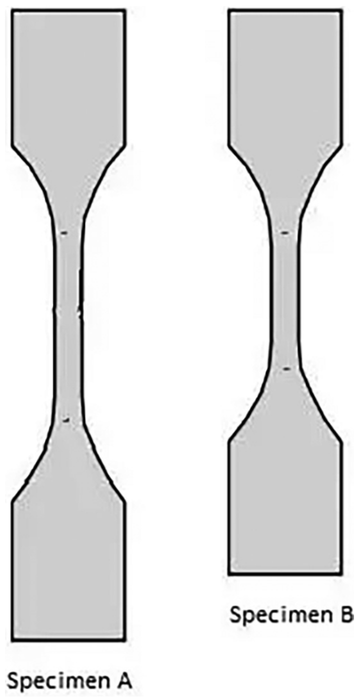

Fig. 4. Tensile and compression test specimen.

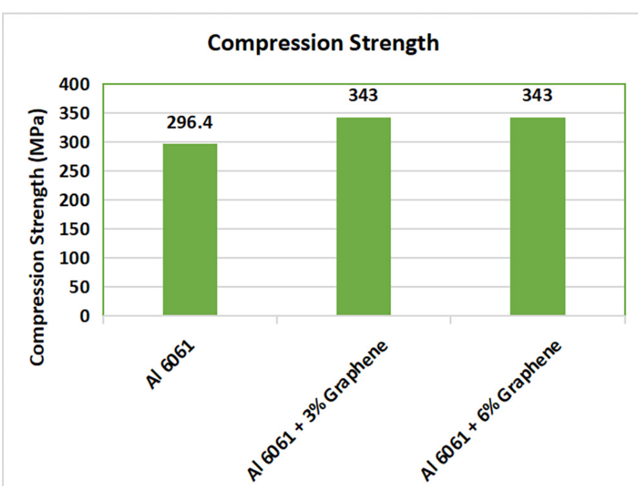

Fig. 5. Compression test.

an essential parameter [31]. Solidification plays an important role in analysing the properties of the fabricated metal matrix composite of silicon carbide-reinforced aluminium [32].

3.1. Sample removal

The final stage of the process sequence of stir casting is the removal of samples from the mold. The process of solidification ends after a predetermined time period. After the solidification time, the samples are removed from the mould flask. The samples are removed from the mould as described in the above method of removal. The samples that were removed from the mould are kept open in the atmosphere. This is done in order to decrease the temperature of the fabricated samples, as the removed samples are in very hot condition. The fabricated samples of various compositions of Al-graphene MMC are ready for various cycles of testing. These samples are subjected to mechanical tests such as tensile tests, compression tests, and hardness tests. The outline for stir casting gives the general steps and processes involved in this method of casting. The process of stir casting involves the following steps:

- Metal is melted in a coal-fired furnace at a temperature range of 650–750 °C.
- The metal mixture is poured into the cavity of the mold after it has reached the desired shape.
- The molten liquid is poured into the cavity and then given time to harden. Typically, 30 s are provided for solidification.
- The removal is done without the help of any bars or sticks.
- The final samples fabricated are ready for cycles of tests that are made to analyze the various parameters and properties of the composite material used for fabricating the samples.

4. Various types of testing

4.1. Tensile test

A sample is put through tensile testing, also known as tension testing, which involves applying a controlled tension to it until the sample breaks. The results of the tests are frequently used as a quality control measure whenever a material is being chosen for an application. The ultimate tensile strength, maximum elongation and area reduction, Young's modulus, and Poisson's ratio can all be directly determined through tensile testing. Biaxial tensile testing is necessary because, most of the time, uniaxial tensile testing is used to figure out the mechanical properties of materials and fabrics that are isotropic. In order to investigate the mechanical behaviour of the MMCs in accordance with ASTM standards, tensile tests were carried out utilising the Universal Tensile Testing Machine (UTM). At 3 % weight, it is shown that the tensile strength and yield strength improve.

Tensile tests are performed on the fabricated samples to determine the tensile strength of the samples. It was noted that the tensile value for Al 6061 + 6 % of graphene was greater than the Al 6061 + 3 % of graphene samples. Pure aluminium samples are observed with the lowest values among the three samples. The tensile values are increased in proportion to the composition percentage. The tensile values for the composites are given in Table 2.

4.2. Compression test

The behaviour of materials when subjected to crushing stresses can be determined through the use of a compression test. The specimen is subjected to compression, and the results are recorded at a number of different loads. Determine the elastic limit, the proportional limit, the yield point, the yield strength, and, for some materials, the compressive strength using the computed and plotted compressive stress and strain (see Table 3).

A sample specimen is said to be in tension when it is loaded in a way that causes it to extend. On the other hand, a material is said to be in compression if it shortens and compresses. On an atomic level, solid molecules or atoms constantly seek an equilibrium state, but due to the space between them, forces that oppose either tension or compression develop throughout the entire substance.

Table 2
Tensile strength values.

Materials	Tensile strength (MPa)
Pure Al 6061	149.76
Al 6061 + 3 % grapheme	156
Al 6061 + 6 % grapheme	175

Table 3
ASTM standard.

Loading	ASTM standard
Tension	D3039
Compression	D3410

Therefore, the behaviours present at the atomic level are comparable.

In a compression test, the material is compressed, squashed, crushed, or flattened by opposing pressures pushing inward on the specimen from opposite sides. The test sample is often positioned between two firm metal bearing blocks, which evenly distribute the applied load across the surface area of the test sample's two opposing sides. The plates are then pressed together by a universal testing machine, which flattens the sample. A sample will contract in the direction of the applied pressure and expand in the opposite direction.

The term positive strain is used to describe an object that is loaded in a way that causes it to stretch, whereas the term negative strain is used to describe an object that is stressed in a compressive manner that causes it to shrink. Small sideways deflections that are out of alignment are more likely to buckle under compression than under tension. To determine the compression of the fabricated samples, a compression test is performed. It was noted that the compressive value for Al 6061 + 6 % of graphene samples is higher than that for Al 6061 + 3 % of graphene samples. Pure aluminium samples are observed with the lowest values among the three samples. The compression range of nanocomposite material values increases in proportion to the composition percentage. The compression values for the composites are given in Table 4.

The sample or component is compressed during compression testing between two moving platens. To measure load and displacement, a load cell and an extensometer or strain gauge are utilised. Testing a material or component's load-bearing capacity under compressive stresses may be done using compression tests. For instance, while designing towers, columns, bridges, and other load-bearing structures, compression pressure is taken into consideration. Both performing the test and getting the test samples ready are relatively straightforward. Depending on the availability of the sample materials, solid specimens of different lengths (short, medium, and long) may be employed, according to ASTM.

Depending on the test place, there are two types of material compression testing: static and dynamic modes. While dynamic testing occurs at speeds more than 10 mm min-1, static testing needs rates less than 1 mm min-1. Axial and plane strain compression testing are other subcategories of static testing. The yield strength, ultimate strength, and modulus of materials used in the design of equipment structures and other structures may be obtained from the axial compression tests. The flow stress characteristics of a material may be evaluated using the plane strain compression test, which is crucial for choosing/sizing the machinery used in the production process, such as rolling, forging, and extrusion.

4.3. Density

The archimedean principle was used to conduct an experimental investigation of the densities of the prepared specimens. The most basic way to figure out the density of a composite sample is to measure its mass and volume.

Table 4
Compression strength values.

Materials	Compression strength (MPa)
Pure Al 6061	296.4
Al 6061 + 3 % graphene	343
Al 6061 + 6 % graphene	343

Table 5
Density values.

Materials	Density values (kg/m^3)
Pure Al 6061	2.7
Al 6061 + 3 % graphene	2.61
Al 6061 + 6 % graphene	2.73

The formula density = mass / volume is used to determine a specimen density value and the density values are given in the below Table 5.

A straightforward procedure may be used to determine the simple mass density of composite materials, or composites composed from two or more different materials whose component densities are known. Divide the percentile contribution of each element or compound to the mixture by 100 to get a decimal value (a number between 0 and 1). Add the density of the associated chemical or element to each decimal.

5. Conclusion

The following are the findings of the current investigation:

- When the tensile, compression, hardness, and density of stir-produced Al alloy 6061 with graphene-reinforced composites were compared to those of base Al alloy 6061, the results showed that base Al alloy 6061 + 6 % graphene was clearly better.
- Al-graphene particles dispersed in an aluminium matrix increase the material's tensile strength.
- The length of the material gets shorter as the particle weight goes up. This shows that graphene makes materials more brittle.
- The incorporation of alpha-graphene particles results in an increase in the tenacity of the matrix.
- With this metal matrix composite, the material's tensile strength is improved.
- Using stir casting, it was possible to make aluminium matrix composites with graphene and Al 6061 particles that were mostly spread out in the same way throughout the material.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] J. Kumaraswamy, K.C. Anil, V. Shetty, C. Shashishekar, Wear behaviour of the Ni-Cu alloy hybrid composites processed by sand mould casting, Adv. Mater. Process. Technol. (2022) 1–17, https://doi.org/10.1080/2374068X.2022.2092684.

[2] K.C. Anil, J. Kumaraswamy, Akash et al., Experimental arrangement for estimation of metal-mold boundary heat flux during gravity chill casting, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2022.07.399.

[3] R. Sridhar, S. Baskar, V.S. Shaisundaram, K. Karunakaran, M. Ruban, S. Joseph Irudaya Raja, Design and development of material behavior of line follower automated vehicle, Mater. Today:. Proc. 37 (2021) 2193–2195.

[4] M. Ruban, S. Sivaganesan, C. Dhanasekaran, Experimental Investigation on Straight Through Solar Salt Water Desalination System Analysis in Different Pcm Materials, Int. J. Mech. Prod. Eng. Res. Develop. (IJMPERD) 8 (3) (June 2018) 67 80.

[5] J. Kumaraswamy et al., Thermal Analysis of Ni-Cu Alloy Nanocomposites Processed by Sand Mold Casting, & Advances in Materials Science and Engineering, vol. 2022, Article ID 2530707, 11 pages, 2022. https://doi.org/10.1155/2022/2530707.

[6] R.S. Harish, M. Sreenivasa Reddy, J. Kumaraswamy, Mechanical behaviour of Al7075 alloy Al2O3/E-Glass hybrid composites for automobile applications, Mater. Today: Proc., https://doi.org/10.1016/j.matpr.2022.08.460.

[7] S. Arunkumar, M. Chandrasekaran, V. Muthuraman, T. Vinod Kumar, Study properties and mechanical behavior of the shaft material 16MnCr5, Mater. Today:. Proc. 37 (2021) 2458–2461.

[8] J. Kumaraswamy, K.C. Anil, V. Shetty, Development of Ni-Cu based alloy hybrid composites through induction furnace casting, Mater. Today: Proc., https://doi.org/10.1016/j.matpr.2022.09.215.

[9] K.C. Anil, J. Kumarswamy, M. Reddy, B. Prakash, Mechanical Behaviour and Fractured Surface Analysis of Bauxite Residue & Graphite Reinforced Aluminium Hybrid Composites, Frattura ed Integrità Strutturale 62 (2022) 168–179, https://doi.org/10.3221/IGF-ESIS.62.12.

[10] T. Vinodkumar, M. Chandrasekaran, P. Vivek, S. Arunkumar, S. Padmanabhan, Evaluating the mechanical properties of snake grass fibre and sisal fibre hybrid composites by injection moulding method, Int. J. Vehicle Struct. Syst. 11 (3) (2019) 236–240.

[11] J. Kumaraswamy, V. Kumar, G. Purushotham, A review on mechanical and wear properties of ASTM a 494 M grade nickel-based alloy metal matrix composites, Mater. Today:. Proc. 37 (2021) 2027–2032, https://doi.org/10.1016/j.matpr.2020.07.499.

[12] R. Dhinakaran, R. Muraliraja, R. Elansezhian, S. Baskar, S. Satish, V.S. Shaisundaram, Utilization of solar resource using phase change material assisted solar water heater and the influence of nano filler, Mater. Today:. Proc. 37 (2021) 1281–1285.

[13] A. Prabhakaran, K. Sridhivya Krishnan, R. Dhinakaran, S. Baskar, V.S. Shaisundaram, Analysis of the efficiency of an automotive alternator by replacing mild steel into aluminum as a material for rotor, Mater. Today:. Proc. 37 (2021) 1269–1273.

[14] K. Jayappa, V. Kumar, G. G. Purushotham, Effect of reinforcements on mechanical properties of nickel alloy hybrid metal matrix composites processed by sand mold technique, Appl. Sci. Eng. Progress 14(1) (2021) 44–51, https://doi.org/10.14416/j.asep.2020.11.001.

[15] J. Kumaraswamy, V. Kumar, G. Purushotham, Thermal analysis of nickel alloy/ Al2O3 /TiO 2 hybrid metal matrix composite in automotive engine exhaust valve using FEA method, J. Therm. Eng. 7 (3) (2021) 415–428, https://doi.org/10.18186/thermal.882965.

[16] A. Parthiban, V. Vijayan, R. Saravanan, T. Sathish, I.J. Isaac Premkumar, Sanjeevi Basker, Experimental Investigation Glass/ sodium oxidanide Treated Banana Fiber Hybrid, International conference on Recent Trends in Mechanical and Materials Engineering (ICRTMME19),AIP Conference Proceedings 2283, 020064 (2020); https://doi.org/10.1063/5.0024982, Published Online: 29 October 2020.

[17] V. Vijayan, T. Sathish, R. Saravanan, I. J. Isaac Premkumar, Sanjeevi Basker, A. Parthiban, Synthesize and Characterizations of Glass / Treated selective Sisal Fiber Hybrid Composite, International Conference on Recent Trends in Mechanical and Materials Engineering (ICRTMME19),AIP Conference Proceedings 2283, 020066 (2020); https://doi.org/10.1063/5.0024985, Published Online: 29 October 2020.

[18] J Kumaraswamy, Vijaya Kumar, G. Purushotham, Evaluation of the microstructure and thermal properties of (ASTM A 494 M grade) nickel alloy hybrid metal matrix composites processed by sand mold casting, Int. J. Ambient Energy, 42 (2021) 1–10. https://www.tandfonline.com/doi/abs/10.1080/01430750.2021.1927836.

[19] S. Baskar, M. Ruban, G. Nethaji, Impact of C 45 material manual gear transmissions in two wheeler, Mater. Today: Proc. (2022).

[20] Sanjeevi Basker, A. Parthiban, R. Saravanan, V. Vijayan, T. Sathish and I.J. Isaac Premkumar, "Influence of Chemical Treatment in Synthesize and Characterization Sisal/Glass Hybrid Composite", International Conference on Recent Trends in Mechanical and Materials Engineering (ICRTMME19), AIP Conference Proceedings 2283, 020065 (2020); https://doi.org/10.1063/5.0024883.

[21] A. Baradeswaran, Effect of graphite content on tribological behaviour of aluminium alloy graphite composite, Eur. J. Sci. Res. 53 (2) (2011) 163–170.

[22] G. Saravanan, K. Subramanian, V. Ananda Krishnan, R. Sankaranarayanan, Effects of particulate reinforced aluminium metal matrix composite, Mechanics and Mechanical Engineering, Lodz Univ. Technol. 19(1) (2015) 23–30.

[23] K.R. Suresh, H.B. Niranjan, P. Martin Jabraj, M.P. Chowdaiah, Tensile and wear properties of aluminium composites, Wear 255 (2003) 638–642.

[24] D. Singla, S.R. Mediratta, Evaluation of mechanical properties of Al7075-Fly ash composite material, international journal of innovative research in science, Eng. Technol. 2 (4) (2013) 951–959.

[25] D.M. Aylor., 1982. Metals Hand Book V-13 & Vol. 19. ASM Metals Park, OH. pp. 859–863.

[26] Han Jian-min, Wu Zhao-ling, Cui Shi-haia, Li Wei-Jing, DuYong-ping, 2006, Investigation of defects in Al2O3/A356 composites made by a stir casting method, J. Ceramic Process. Res. 8(1) 74–77.

[27] T.V. Christy, N. Murugan, S. Kumar, A Comparative Study on the Microstructures and Mechanical Properties of Al 6061 Alloy and the MMC Al 6061/TiB2/12P, J. Miner. Mater. Charact. Eng. 9 (1) (2010) 57–65.

[28] S.K. Chaudhury, A.K. Singh, C.S. Sivaramakrishnan, S.C. Panigrahi, Wear and friction behavior of spray formed and stir cast Al–2Mg–11TiO2 composites||, Wear 258 (2005) 759–767.

[29] Rakesh Kumar Yadav, Nabi Hasan, Ashu Yadav, Studies on Mechanical Properties of Al -Based Cast Composites, IJCSMS Int. J. Comput. Sci. Manage. Stud. 11 (02) (2011).

[30] M.V. Krishna, A.M. Xavior, An investigation on the mechanical properties of hybrid metal matrix composites, Procedia Eng. 97 (2014) 918–924.

[31] C. Parswajinan, B. Vijaya Ramnath, M. Vetrivel, M. Aswin, B. Mohana Vignesh, Mechanical behavior of aluminium metal matrix composite, Adv. Sci. Eng. Med. 10 (3–4) (2018) 395–397.

[32] R.R. Mishra, A. Panda, A.K. Sahoo, R. Kumar, Research progress on nano-metal matrix composite (NMMC) fabrication method: A comprehensive review, Mater. Today:. Proc. 56 (2022) 2104–2109.