International Journal of Multidisciplinary Research and Growth Evaluation.

Mechanical properties of Aluminium-Ceramic-waste particulate composite produced using Stir casting Technology

Evarastics Polycarp [1*], Lasisi Shaibu [2], Mahdi Sani Udu [3], Muyideen Abdulkadir [4], Lasisi Isa Olusegun [5]

[1-3] Department of Metallurgical Engineering Technology, Waziri Umaru Federal Polytechnic, Birnin Kebbi, Kebbi State, Nigeria

[4-5] Department of Mechanical Engineering Technology, Waziri Umaru Federal Polytechnic, Birnin Kebbi, Kebbi State, Nigeria

* Corresponding Author: **Evarastics Polycarp**

Article Info

ISSN (online): 2582-7138
Impact Factor: 5.307 (SJIF)
Volume: 04
Issue: 05
September-October 2023
Received: 28-08-2023;
Accepted: 18-09-2023
Page No: 534-538

Abstract

The use of waste products/materials in research has continued to gain ground because it enhances the maximum utilization of materials and promotes a clean and healthy environment. In this work, ceramic waste from floor-tiles has been collected and used as a reinforcement to form an aluminium matrix composite using stir-casting technology. The tiles were ground into powder and the particle size below 0.063mm was selected and subjected to XRD and XRF analyses to ascertain its composition. The percentage weight fractions (%wt) of the reinforcement (R) added in aluminium matrix were; 1.0, 2.0, 3.0, 4.0, 5.0 and 6.0 wt%R. Also, a constant amount of 1.0 wt% magnesium was added to evaluate the effect of Mg on the samples. The samples produced were subjected to Vicker's hardness and tensile tests. The results of the XRD and XRF analyses showed that the main contents of the floor-tile were Al_2O_3, SiO_2, CaO, and TiO; while other complex ceramic compounds in smaller amounts were also present. The hardness results showed a gradual increase with the amount of reinforcement from 30.1 VHN in unreinforced aluminium to 59.6 VHN in the sample containing 6.0wt%R. Similarly, the tensile test results showed an increase from 42.4N/mm^2 in the unreinforced sample to 78.9N/mm^2 in the sample containing 4.0 wt%R then decreased to 68.5N/mm^2 in the sample containing 6.0 wt%R. With the addition of 1.0 wt%Mg, the minimum and maximum hardness and tensile strength values were 32.6 and 62.1 VHN; and 44.2 and 89.1N/mm^2 respectively. The results show that the prospect of using waste floor-tiles to improve the mechanical properties of aluminium matrix composite for engineering applications is promising.

Keywords: Aluminium, composite, waste floor-tiles, stir-casting, mechanical properties

Introduction

The use of locally sourced materials such as agricultural waste, by-products from manufacturing and other sources has been the focus of research for advanced materials to meet the needs of the moment (Adeyanju *et al*., 2023; Fayomi *et al*., 2022; Mydin *et al*., 2023; Nasr *et al*., 2020; Ohenhen and Igbinere, 2021; Okon *et al*., 2020; Talabi *et al*., 2022) [1, 5, 16, 17, 19, 20, 28]. This helps to maximize the use of materials and a way of managing waste disposal. The recent advancement in technology requires special materials with superior properties. These required properties may include wear resistance, hardness, corrosion resistance, lightweight but high strength, high-temperature properties, low coefficient of thermal expansion, etc.

Aluminium metal is always a good candidate for applications where lightweight is required but in its monolithic nature, it usually lacks the requisite strength and other properties needed. For this reason, certain reinforcements (R) are usually added to aluminium matrix in a marriage that gives birth to an aluminium matrix composite that is characterized by improved strength in addition to the lightweight needed especially for applications in aerospace, electronics, automobiles and other industries (Aigbodion and Hassan, 2007) [2]. Particulate reinforced aluminium matrix composite has the following characteristics: high elastic modulus, specific strength, low coefficient of thermal expansion and high wear resistance (Zheng *et al*., 2020).

One of the advantages of composite materials is that their properties can easily be tailored to meet any given requirements. Some of the locally sourced materials that have been used as reinforcement in different metal matrices include: Coconut shell ash (Kumar *et al*., 2016; Madakson *et al*., 2012) [12, 13], rise husk ash (Alaneme and Sanusi, 2015; Olorunyolemi *et al*., 2022; Shaikh *et al*., 2019) [3, 21], sugarcane bagasse ash (Balaji *et al*., 2022; Hernández *et al*., 2019; Kamble and Kulkarni, 2019) [4, 6, 10], palm kernel shell ash (Ikele *et al*., 2022; Oyedeji, *et al*., 2022) waste bamboo wood ash (Sathish *et al*., 2022) [8], and ceramic waste (Zheng *et al*., 2020); just to mentioned but a few.

Zheng *et al*. (2020) investigated the wear behaviour of aluminium matrix composite using ceramic waste (SiC) as reinforcement. The result gave a high frictional coefficient potentially making it a good candidate for use as a brake disc. In other research using Al_2O_3 as a reinforcement in the aluminium matrix, it was found that the hardness and tensile strength of the composites increased with the amount of reinforcement (Jayappa *et al*., 2021; Kok, 2005; Sathish *et al*., 2019) [9, 11, 25].

The effect of SiO2 as reinforcement in an aluminium matrix produced using stir-casting technology has also been studied (Mugutkar *et al*., 2022; Saini *et al*., 2023) [15, 23]. The effect of TiO as a reinforcement in the aluminium matrix has also been studied (Hugar *et al*., 2022; Maganti & Potturi, 2023; Nithya *et al*., 2023) [7, 14, 18]. The results all show an increase in tensile and harness properties with the amount of the different reinforcements used. In this work, however, the focus is to use waste floor-tiles as a reinforcement in an aluminium matrix using stir casting technology and to evaluate its influence on the tensile strength and hardness of the composite produced.

Materials and method

Materials

The materials used in this work include waste floor-tiles collected from a retail shop, aluminium cable obtained from Power Holding Company Ltd., Birnin Kebbi, Nigeria and magnesium powders.

Procedures

The detailed procedure on how this work was carried out is hereby presented starting from grinding of the tiles and selection of the particle size of the reinforcement, stir-casting process and all the various tests conducted.

Preparation of reinforcement

The broken floor-tiles were taken to Katsina Polytechnic; Katsina State, Nigeria where it was crushed and ground into powder. The powder was screened using a set of mechanical sieves. The powder particles that passed through the 0.063mm sieve size were collected and used as the reinforcement in this work.

XRD and XRF analyses of the ceramic Powder

To verify the content of the waste floor-tiles, the powder samples were taken to the National Steel Council, Kaduna, Nigeria where the samples were analyzed using XRD and XRF.

Production of the test samples using the stir-casting technique 250.0g of aluminium wire inside a crucible was heated to the temperature of about 750oC in a charcoal-fired open-hearth furnace. The slag formed on the molten metal was skimmed off then the molten metal was stirred manually to produce a vortex while 2.5g (1.0wt%) of the reinforcement was added and stirred for five (5) minutes before the liquid metal was poured into three cylindrical mould cavities of length and diameter 130 mm 11.70 mm respectively to produce three samples for each composition. The composition of the reinforcement was varied thus: 1.0 wt%, 2.0 wt%, 3.0 wt%, 4.0 wt%, 5.0 wt%, and 6.0 wt%, of the charge. The entire process was repeated with the constant addition of 1.0 wt% of magnesium to all the compositions above to evaluate the impact of magnesium on the samples. The amount of reinforcement used was limited to 6.0 wt% because of the manual stirring used.

Samples preparation and tensile test

The samples produced were machined to the standard gauge length and diameter of 45mm and 10mm respectively as required by the universal tensile testing machine used. The sample view is shown in Figure (1) below.

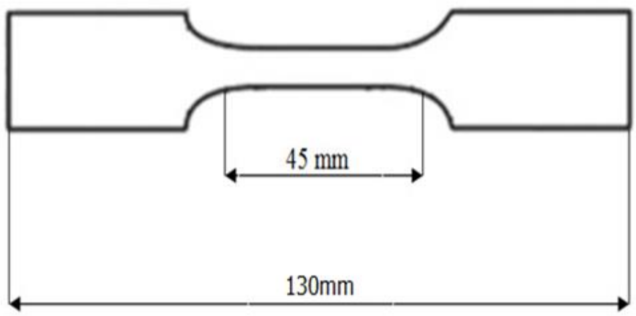

Fig 1: Plane view of the tensile test sample

The tensile test was conducted using a universal tensile testing machine at the Kebbi State University of Science and Technology, Aleiro, Kebbi State, Nigeria. Each of the samples was mounted on the machine and a load of 20KN was applied on it. Each specimen underwent a uniaxial tension, which caused the elongation and fracture of the samples. The fracture loads were recorded and used to determine the tensile strength values of the samples.

Vicker's Hardness Test

Small portions of the test samples were cut and ground using emery papers and later polished. The polished surfaces were placed on the Vicker's hardness machine, such that the indicator (diameter cone) was forced on the test samples under a preliminary minor load of 10kgf. This process was carried out at three different positions for each sample for accuracy. The average Vicker's hardness values (VHN) of the three readings were calculated and recorded for each composition.

Results and Discussion

Results

The XRF result of the reinforcement.

The XRF result of the reinforcement; their amounts in mole percent (%) is presented in Table (1). The results reveal high amounts of SiO2 and Al2O3 that are known for their hardness and refractoriness.

Table 1. The XRF component Result of the reinforcement

Component	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	TiO_2	Others
Mole %	77.26	17.58	5.54	3.30	1.90	0.83	Balance

XRD result of the reinforcement.

The XRD result of the reinforcement is represented by the pie chart in Figure (1) below.

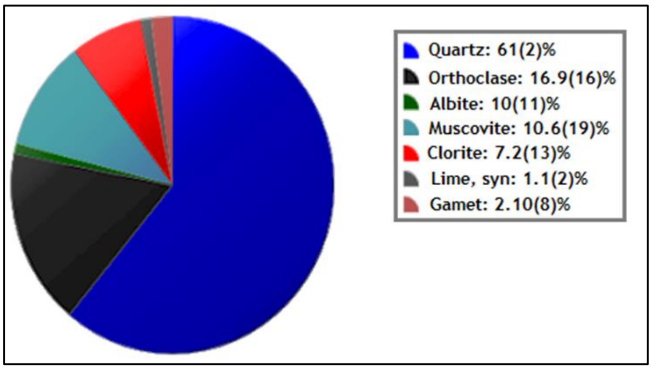

Fig 1: XRD result showing the different phases present in the reinforcement

The chemical formula of the different phases on the pie chart above and their figure of merits are presented in Table (2) to give a better view of the elemental/component compositions of the reinforcement.

Table 2: Phase names and formulas of the compounds identified by XRD

Phase Name	Formula	Figure of merit
Quartz	SiO_2	1.779
Orthoclase	Al_2O_3-K_2O_6-SiO_2	1.936
Albite	$NaAlSi_3O_8$	3.474
Muscovite	$H_2KAl_3(SiO_4)_3$	3.223
Chlorite	$(Mg,Fe)_5(Al, Si)_5O_{10}$	3.429
Lime, syn	CaO	2.911
Gamet	3(Ca, Fe, Mg)O(Al, Fe……..)	2.850

The XRD results in Figure (1) and Table (2) corroborate the XRF results presented in Table (1). At a glance, the compounds; Al2O3 and SiO2 were revealed by both analyses as well as their elemental components. In addition, the XRD result also revealed other complex compounds associated with the reinforcement.

Hardness Test Result

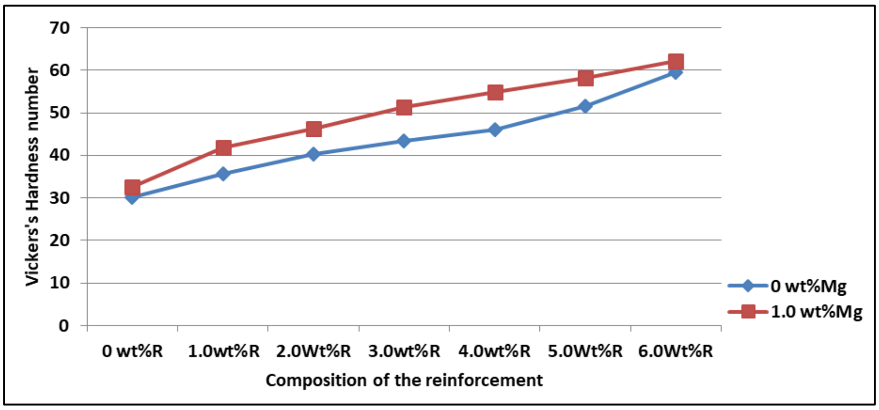

Figure 2: Effect of Reinforcement on Hardness of the samples

The results of the hardness test of the samples in Figure (2) show that the hardness values of the samples increase with the weight fraction of reinforcement. The unreinforced aluminium sample recorded the lowest hardness value while the sample containing 6.0 wt%R gave the highest hardness value.

Tensile Test Results

The values of the tensile test results were plotted against the amount of reinforcement added as shown in the figure below.

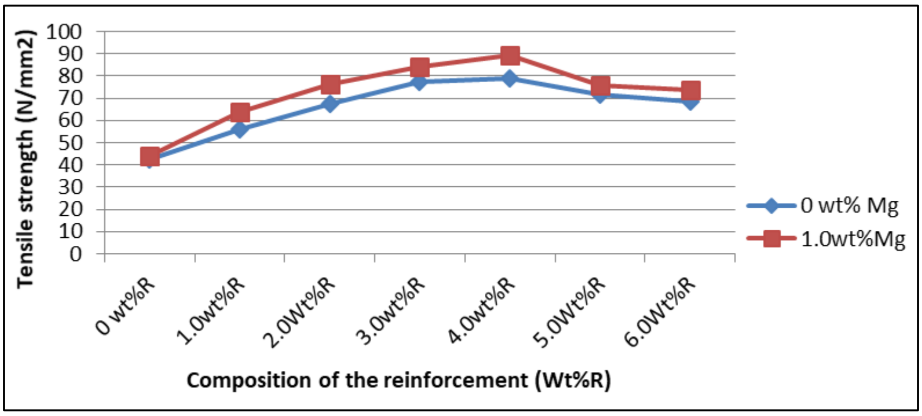

Fig 3: The effect of reinforcement on the tensile strength of the samples

The results in Figure (3) show a gradual increase in tensile strength values with the weight fraction of reinforcement. The unreinforced sample recorded the lowest tensile value while the maximum tensile strength was observed in the sample containing 4.0wt% reinforcement.

Discussion

The results of XRD and XRF analyses revealed the presence of hard particles; SiO2 and Al2O3 as the major components, also known to be refractory materials. Other hard particles that were revealed include titanium oxide (TiO) and other complex compounds as shown in the Tables. The presence of these hard particles is reflected in the tensile and hardness properties of the composites produced.

The combined effects of the hard particles: Al2O3, SiO2, TiO and other particles caused an increase in the hardness properties of the composite samples. The unreinforced aluminium gave the lowest hardness value of 30.1VHN while the sample containing 6.0 wt%R gave 59.6 VHN. With the addition of 1.0 wt%R, there was an improvement as the unreinforced sample recorded 32.6VHN, about an 8.3% increase; while the sample containing 6.0 wt%R gave 62.1VHN, about a 4.2% increase. The trend in the hardness values of the samples increased with the amount of reinforcement; which is consistent with the findings of Kok (2005) [11], Mugutkar *et al*. (2022) [15] and Saini *et al*. (2023) [23]. The presence of magnesium acts as a wetting agent in the aluminium matrix (Schaffer & Hall, 2002) [26]; this helps to improve the bonding between the aluminium matrix and the reinforcement as observed in the slight increase in the hardness values of the samples when 1.0 wt%Mg was added in the samples.

The tensile strength values of the samples also followed the same trend as those of the hardness. The unreinforced aluminium sample gave the lowest tensile strength value equivalent to 42.43N/mm2, which increased to 44.19N/mm2 when 1.0 wt%Mg was added; about a 4.1% increase. In samples containing 1.0 wt%R and 4.0wt%R, the tensile strength values were 56.15 and 78.17N/mm2 respectively. The tensile strength values were then reduced to 68.15N/mm2 in the sample containing 6.0 wt%R. When 1.0 wt%Mg was added to each of the compositions there was a general increase in tensile strength values from 63.63N/mm2 to 89.10N/mm2 in samples containing 1.0 wt%R and 4.0 wt%R respectively; equivalent to 13.3% and 14.0% increments respectively.

The increment in the tensile strength values, therefore, is attributed to the combined effects of Al2O3, SiO2, and TiO in the reinforcement since each of them is capable of increasing the tensile strength values in aluminium matrix composite as shown in the works of Kok (2005) [11], Magutkar *et al*. (2022) and Saini *et al*. (2023) [23]. As already mentioned, the presence of magnesium facilitates wetting of the reinforcement by aluminium matrix (Schaffer & Hall, 2002) [26], as reflected in the samples. The highest tensile strength obtained in this work was 89.1N/mm2 in the sample containing 4.0 wt%R-1.0wt%Mg. One of the reasons for the decrease in tensile strength values above this composition could be due to the manual stirring method used as no mechanical stirrer was available. The study revealed that the use of waste floor-tiles is beneficial in improving the hardness and tensile strength of aluminium matrix composite.

Conclusion

From the results obtained and the discussions above, it is apt to summarize as follows: The reinforcement obtained from the waste floor-tiles is composed, majorly, of Al2O3, SiO2 and TiO. These ceramics, known to be hard particles, caused an increase in the hardness and tensile strength values of the composite samples produced. The sample containing 6.0 wt%R-1.0 wt%Mg gave the highest hardness value while the sample containing 4.0 wt%Mg gave the highest tensile strength. The results obtained in this study show that the potential of using this waste product to enhance the mechanical properties of aluminium matrix composite is promising. However, for further study, the use of a mechanical stirrer will accommodate a higher amount of reinforcement above 6.0 Wt%R and enhance equitable distribution of the reinforcement in aluminium matrix; which could give higher hardness and tensile strength values than the ones obtained in this work.

Acknowledgement

We wish to acknowledge the followings who contributed to the success of this work: Victoria Francis, Nasir Abubakar Tura, Ibrahim Ishaku, Sagir Abubakar, and Oladoja Rilwan Kolade.

References

1. Adeyanju IA, Alabi SO, Esan AO, Omodunbi BA, Bello OO, Fanijo S. Design and prototyping of a robotic hand for sign language using locally-sourced materials. Scientific African. 2023; 19:e01533.
2. Aigbodion VS, Hassan SB. Effects of silicon carbide reinforcement on microstructure and properties of cast Al–Si–Fe/SiC particulate composites. Materials Science and Engineering: A. 2007; 447(1-2):355-360. doi: http://dx.doi.org/10.1016/j.msea.2006.11.030
3. Alaneme KK, Sanusi K. 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. 2015; 18(3):416-422.
4. Balaji A, Gomathi K, Rajan UN, Mithil J, Vinunath A, Vagish R. Effect of particle size on mechanical behavior of sugarcane bagasse ash reinforced AlSi10Mg alloy. Materials Today: Proceedings. 2022; 66:1276-1283.
5. Fayomi O, Sojobi J, Nkiko M, Akande I, Noiki A. An overview of the influence of agro waste reinforcement on aluminium matrix composites. Paper presented at the AIP Conference Proceedings, 2022.
6. Hernández-Ruiz J, Pino-Rivero L, Villar-Cociña E. Aluminum matrix composite with sugarcane bagasse ash as reinforcement material. Revista Cubana de Física, 2019; 36(1):55-59.
7. Hugar N, Narayana BV, Waddar S. Mechanical behaviour of stir cast TiO2/Redmud/Al6061 metal matrix composites. Materials Research Express. 2022; 9(11):116509.
8. Ikele US, Alaneme KK, Oyetunji A. Mechanical behaviour of stir cast aluminum matrix composites reinforced with silicon carbide and palm kernel shell ash. Manufacturing Review. 2022; 9:12.
9. Jayappa K, Kumar V, Purushotham GG. Effect of reinforcements on mechanical properties of nickel alloy hybrid metal matrix composites processed by sand mold technique. Applied Science and Engineering Progress.

2021; 14(1):44-51.
10. Kamble A, Kulkarni S. Microstructural examination of bagasse ash reinforced waste aluminium alloy matrix composite. Paper presented at the AIP Conference Proceedings, 2019.
11. Kok M. Production and mechanical properties of Al2O3 particle-reinforced 2024 aluminium alloy composites. Journal of Materials Processing Technology. 2005; 161(3):381-387.
12. Kumar A, Kumar K, Saurav S, Raju SS. Study of physical, mechanical and machinability properties of aluminium metal matrix composite reinforced with coconut shell ash particulates. Imperial Journal of Interdisciplinary Research. 2016; 2(2454):1362.
13. Madakson P, Yawas D, Apasi A. Characterization of coconut shell ash for potential utilization in metal matrix composites for automotive applications. International journal of engineering science and technology. 2012; 4(3):1190-1198.
14. Maganti NVR, Potturi RR. Investigation on Mechanical and Machinability Properties of Aluminium Metal Matrix Composite Reinforced with Titanium Oxide (TiO2) and Graphite (Gr) Particles. Trends in Sciences. 2023; 20(11):5682-5682.
15. Mugutkar H, Tamiloli N, Kohir VV. Comparative Analysis of Mechanical Studies of Al7075 Hybrid Metal Matrix Composites as a Functionality of SiO2% in RHA. Academic Journal of Manufacturing Engineering, 2022, 20(2).
16. Mydin MAO, Abdullah MMAB, Sor NH, Omar R, Dulaimi A, Awoyera PO, *et al*. Thermal conductivity, microstructure and hardened characteristics of foamed concrete composite reinforced with raffia fiber. Journal of Materials Research and Technology, 2023.
17. Nasr MS, Ali IM, Hussein AM, Shubbar AA, Kareem QT, AbdulAmeer AT. Utilization of locally produced waste in the production of sustainable mortar. Case Studies in Construction Materials. 2020; 13:e00464.
18. Nithya M, Pritima D, Vijayalakshmi S, David DB, Muthukumar K, Veerappan G, *et al*. Machine learning assisted investigation on properties of TiO2 reinforced aluminium metal matrix composites. Materials Today: Proceedings. 2023; 74:80-84.
19. Ohenhen I, Igbinere S. The Use of Locally Sourced Ginger as Weighting Material in Drilling Mud. Journal of Energy Technology and Environment, 2021, 3(1).
20. Okon AN, Akpabio JU, Tugwell KW. Evaluating the locally sourced materials as fluid loss control additives in water-based drilling fluid. Heliyon, 2020, 6(5).
21. Olorunyolemi OC, Ogunsanya OA, Akinwande AA, Balogun OA, Saravana Kumar M. Enhanced mechanical behaviour and grain characteristics of aluminium matrix composites by cold rolling and reinforcement addition (rice husk ash and coal fly ash). Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 2022, 09544089221124462.
22. Oyedeji E, Dauda M, Yaro S, Abdulwahab M. The effect of palm kernel shell ash reinforcement on microstructure and mechanical properties of Al-Mg-Si metal-matrix composites. Proceedings of the institution of mechanical engineers, Part C: journal of mechanical engineering science. 2022; 236(3):1666-1673.
23. Saini S, Gupta A, Mehta AJ, Pramanik S. Effect of graphite and rice husk-derived SiO2 on mechanical and thermal properties of re-sintered aluminium-based metal matrix hybrid nanocomposites. Journal of Thermal Analysis and Calorimetry. 2023; 148(6):2335-2344.
24. Sathish T, Kumar SD, Ravichandran M, Mohanavel V, Kumar SS, Rajkumar S, Subbiah R. Waste food cans waste bamboo wood based AA8079/SS304/bamboo wood ash hybrid nanocomposite for food packaging. Key Engineering Materials. 2022; 928:69-78.
25. Sathish T, Saravanan S, Vijayan V. Effect of reinforced aluminium alloy LM30 with pure ceramic particles to evaluate hardness and wear properties. Materials Research Innovations, 2019.
26. Schaffer GB, Hall BJ. The influence of the atmosphere on the sintering of aluminum. Metallurgical and Materials Transactions A. 2002; 33(10):3279-3284.
27. Shaikh MBN, Raja S, Ahmed M, Zubair M, Khan A, Ali M. Rice husk ash reinforced aluminium matrix composites: fabrication, characterization, statistical analysis and artificial neural network modelling. Materials Research Express. 2019; 6(5):056518.
28. Talabi HM, Ojomo A, Folorunsho OE, Akinfolarin J, Pradeep Kumar J, Mohan RR, Kumar MS. Development of hybrid aluminium alloy composites modified with locally sourced environmental wastes. Advances in Materials and Processing Technologies, 2022, 1-18.
29. Zheng K, Wei X, Yan B, Yan P. Ceramic waste SiC particle-reinforced Al matrix composite brake materials with a high friction coefficient. Wear. 2022; 458:203424.