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Characterization of Aluminium 2024 Composites Reinforced with Silicon Carbide and Fly Ash

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ABSTRACT:

Aluminium 2024 alloy is extensively applied in the aerospace and structural industry because it has a high strength-to-weight ratio, but its mechanical properties could be improved, and its weight could also be decreased, which is also a vital engineering consideration. The current research successfully developed Aluminium 2024-based hybrid metal matrix composites using the stir casting method, reinforcing them with Silicon Carbide (SiC) and Fly Ash (FA) particles. The reinforcements were added in different weight proportions to determine their interactive effect on mechanical and physical properties. The artificially manufactured composites were tested on tensile testing, Brinell hardness testing and density testing in accordance with the standard ASTM. The experimental observations showed a steep increase in tensile strength and hardness with an increase in the reinforcement content and a decreasing trend in the density as a result of low-density fly ash. The tensile strength was the lowest, and the hardness was the highest in the unreinforced Aluminium 2024 alloy with the highest density. The hybrid composite of 5 wt.% SiC with 5 wt.% FA showed the best overall performance because it reached the highest tensile strength, of about 290 N/mm^2, the highest hardness, measuring about 94 BHN and the lowest density, at about 2.09 g/cm^3. This is credited to the increased mechanical performance being due to the transfer of loads effectively, plastic deformation being inhibited by hard SiC particles, and the use of fly ash to improve the packing of particles. The findings indicate that Al2024-SiC-FA hybrid composites are potential high-strength composites that can be used in automotive and aerospace engineering in lightweight applications.

KEYWORDS: *Aluminium 2024; Hybrid metal matrix composite; Silicon carbide; Fly ash; Stir casting; Mechanical properties.*

I.INTRODUCTION

Aluminium alloys have been known to be essential materials in the aerospace, automobile and structural engineering designs, owing to their low density, excellent corrosion resistance, and a desirable strength-weight ratio. Among them, an important place is held by Aluminium 2024 alloy due to its great specific strength and high fatigue resistance that allow it to be applied in structural elements of aircraft, fuselage frames, and wing assemblies. Although these exist, the increasing demand for lightweight structures that have improved mechanical performance has revealed some shortfalls of monolithic Aluminium 2024, especially with regard to wear resistance, surface hardness and further weight optimisation. These limitations have encouraged the widespread research on the development of sophisticated composite materials of aluminium.

Metal matrix composites (MMCs) have become one of the potential materials that can address the shortcomings of traditional alloys and offer improved geometries through the incorporation of a metallic matrix with appropriate reinforcement phases. It has also been demonstrated that the addition of ceramic particulates to the aluminium matrices has greatly enhanced the mechanical properties of aluminium matrices, such as tensile strength, stiffness, hardness and wear resistance. Particulate-reinforced MMCs in this regard are particularly appealing because they

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have relatively easy preparation pathways, are isotropic, and reasonably costly relative to fibre-reinforced ones. Stir casting has most frequently been accepted as a means of fabrication due to its simplicity, scalability and appropriateness in industrial production.

Silicon carbide (SiC) has been one of the most popular ceramic reinforcements in aluminium-based MMCs due to its high hardness, high thermal stability and excellent interfacial bonding with aluminium matrices. Introduction of SiC particles is really effective in increasing the load transfer mechanisms and limiting plastic deformation to achieve enhanced strength and wear resistance. Nonetheless, the sole application of ceramic reinforcements like SiC can similarly raise the cost of the material and can negatively influence the density and ductility in cases where the reinforcements are applied in larger ratios.

To overcome these problems, hybrid metal matrix composites where various types of reinforcement are used have been of great interest in recent years. One of the secondary reinforcements that has turned out to be viable is fly ash, an industrial waste by-product created as a result of coal-fired thermal power facilities, as it is of low density, extensive availability, and also has economical benefits. Fly ash is not only included when it comes to the reduction of weight but also the development of materials that are sustainable, as it transforms industrial wastes into value-added engineering materials. Fly ash can also be used to complement the strengthening mechanism alongside density and cost penalties when used with SiC.

This paper has used the stir casting method to reinforce Aluminium 2024 alloy with a hybrid blend of Silicon Carbide and Fly Ash to create lightweight alloy composites with superior mechanical characteristics. This is mainly to examine the influence of different SiC and FA content on tensile strength, hardness, and density and determine the best combination of reinforcement that can be used in high-strength and lightweight engineering processes.

II.LITERATURE REVIEW

The active field of research has been on the development of aluminium-based metal matrix composites (MMCs) in the last few decades due to the necessity of lightweight materials with high mechanical and tribological attributes in aerospace, automotive and structural applications. The reinforcement of the aluminium alloys with ceramic particulates and industrial by-products has been widely used by researchers to address these limitations inherent to the monolithic aluminium alloys.

A number of research studies have been conducted on the use of fly ash as a reinforcing agent in aluminium matrix composites owing to its low density, low price, and broad accessibility as an industrial waste. In a study by Rao et al. (2012), reinforced Aluminium 2024 using fly ash particles developed by stir casting was examined, whereby a significant drop in density was observed, and better hardness and compressive strength were attained. Their microstructure analysis showed that fly ash particles were distributed evenly, resulting in better interfacial bonding and mechanical performance. Likewise, David Raja Selvam et al. (2013) researched AA6061-fly ash composite formed by compocasting and noticed that microhardness and tensile strength increased markedly with more fly ash since the particles got homogeneously dispersed and refined as grains.

Kountouras et al. (2015) studied the impact of the fly ash reinforcement with high volume on aluminium matrix composites and obtained improvements in hardness and thermal expansion reduction. They, however, also noted high wear rates at higher fly ash contents as a result of the fragmentation of the particles, meaning that there was a need to have optimum proportions of reinforcement. Dinaharan et al. (2016) used friction stir processing to prepare fly ash-reinforced aluminium composites and reported a great enhancement of grains, high microhardness, and wear resistance. All these studies signify that fly ash can be good in increasing the mechanical properties and decreasing the density, but when over-reinforced, it could have a negative effect.

Simultaneously, the research on the reinforced silicon carbide particles reinforced aluminium alloys has been broadly expanded. Alaneme and Aluko (2012) studied the SiC-reinforced aluminium composites prepared by two-step stir casting and found that the tensile strength and yield strength increased significantly, especially with the increase of the volume fraction of SiC. Rahman and Al Rashed (2014) characterised the composites of aluminium-

SiC using the casting method and found that the hardness and tensile strength enhanced with the content of SiC, yet clustering and porosity were observed at high reinforcement levels. Mohanavel et al. (2018) also affirmed that when the dispersion of the SiC particles is uniform through stir casting, the result is an increase in hardness, yield strength and impact resistance in the aluminium matrix composites.

Although single-reinforcement MMCs have better characteristics, recent research revealed that hybrid metal-alloy composites could be better and more balanced. Ravesh and Garg (2012) examined reinforced aluminium 6061 (with silicon carbide and fly ash) and found that tensile strength, hardness, and toughness improved simultaneously with the mono-reinforced ones. Mahendra Boopathi et al. (2013) have designed hybrid composites of Aluminium 2024 reinforced with SiC and fly ash and have found that the hardness was higher and the density was lower, which shows the synergistic impact of both reinforcements. Dwivedi et al. (2014) were using electromagnetic stir casting to prepare the A356/SiC/FA hybrid composites, and they stated that tensile strength and fatigue behaviour were enhanced because of the even distribution of the particles.

Certain research on the Aluminium 2024 hybrid composites strengthened with SiC and fly ash has emphasised their use in aerospace and automobile applications. Kurapati and Kommineni (2017) reported that wear resistance and wear rate decreased as the percentage of SiC and fly ash in Al 2024 composites was increased. Kurapati et al. (2018) also used Taguchi and ANOVA methods in order to optimise the wear behaviour and proved that the addition of SiC and fly ash contributes greatly to tribological performance. Kumar et al. (2020) also provided evidence that reinforcement content should be increased in the Al 2024-SiC-FA composites to improve hardness and decrease wear rate, with microstructural evidence of well-dispersed particles.

Though these have been made, there is no clear study concerning the overall effect of silicon carbide and fly ash on tensile strength, hardness and density of Aluminium 2024 alloy. In addition, a few systematic experimental studies that determine an ideal hybrid composition of reinforcement through simple and scalable fabrication paths, like stir casting, are still limited. It is these gaps that make up the current study, where the researcher seeks to experimentally measure and determine the mechanical performance of these Al 2024-SiC-FA hybrid metal matrix composites.

III.MATERIALS AND EXPERIMENTAL METHODOLOGY

The current experimental research study aims at the formation and characterisation of hybrid metal matrix composites of Aluminium 2024 that are reinforced with Silicon Carbide (SiC) and Fly Ash (FA). The methodology used in this research also entails proper selection of materials, preparation of composites through liquid metallurgy route, and mechanical characterization through systematic preparation of mechanical characterization through standard testing.

A.MATERIALS SELECTION

Aluminium 2024 alloy was chosen as the base matrix material due to its application in aerospace and structural applications, which is attributed to its good fatigue and high-strength to weight ratio. Copper is the major alloying element in the alloy, making it have strength features. It is, however, relatively easy to harden and has poor wear resistance, so it requires reinforcement in advanced engineering applications.

Silicon carbide particles have been used as the main reinforcement because it is high in hardness, thermal stability and ability to form an interfacial bond with aluminium matrices. The transfer of loads and plastic deformation is reported to be minimized by SiC in improving tensile strength and hardness of aluminium matrix composites (Alaneme and Aluko, 2012; Rahman and Al Rashed, 2014). The secondary reinforcement was chosen as fly ash which is a by-product of thermal power plants that utilise coal as fuel. The drawback of fly ash is that it is a dense and coarse material and therefore is not economical because of its low density and the fine particle size (Rao et al., 2012; Dinaharan et al., 2016).

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Vol. 13, Issue 2, February 2026

To increase the wet endability between the molten aluminium and the ceramic reinforcements, a small amount of magnesium (1.5 wt.%) was added to the molten aluminium to increase interfacial bonding between the aluminium and the ceramic reinforcements and ease agglomeration of particles in processing.

B. FABRICATION OF HYBRID COMPOSITES.

The Aluminium 2024-SiC-FA hybrid metal matrix composites were prepared by the stir cast method, which is one of the most cost-effective and economical liquid-state processing pathways to MMC (Prem Kumar et al., 2019). First, the melted material was Aluminium 2024 alloy ingots that were melted in a resistance-heated furnace and heated above the aluminium melting point. The molten metal was also de-gassed to get rid of the trapped gases and to decrease porosity.

Silicon carbide and fly ash particles that were heated were then progressively added to the molten aluminium, and constant mechanical mixing was performed with the help of a graphite-coated impeller. The stirring rate was kept at a constant level to form a stable vortex, which provides even dispersion of the reinforcement particles in the melt. During stirring, magnesium was added to increase the wettability and increase the bonding between the reinforcements and the matrix. The resulting homogenous molten composite slurry was then spatially disposed in preheated metallic moulds where it was allowed to solidify at ambient temperature.

Composite compositions with five different weight percentages of SiC and FA were made, and an unreinforced Aluminium 2024 sample was selected as a reference. The artificial castings were machined to standard test specimens according to ASTM requirements for mechanical testing.

C.MECHANICAL TESTING PROCESSES.

Tensile testing was conducted on a Universal Testing Machine (UTM) with reference to ASTM E8 standard. The specimens were loaded in uniaxial tensile loading using a constant crosshead speed of 5mm/min until breakage. The final tensile strength values were also determined using the highest load that each specimen supported.

The Brinell hardness testing method was used to measure the hardness as per the ASTM E10 requirements. The indentation was made by pressing a hardened steel ball indenter on the specimen surface with a given load, and the Brinell Hardness Number (BHN) was determined by the diameter of the indent.

The Archimedes principle was used in determining the density of the fabricated composites. The weights of each specimen were determined in air and water, and the density of the specimen was subsequently determined using the standardised equation of buoyancy. It is a measurement system that gives resounding density values of composites of irregular geometry. (Reddy & Srinivas, 2018).

The chosen experimental approach can be considered as reproducible and a credible foundation of the assessment of the effect of SiC and fly ash reinforcements on the mechanical characteristics of Aluminium 2024 hybrid composites.

IV.RESULTS AND DISCUSSION

This part describes and explains the experimental data on the mechanical characterisation of Silicon Carbide (SiC) and Fly Ash (FA) reinforced hybrid metal matrix composites of Aluminium 2024-based. The role of the reinforcements in tensile strength, hardness, and density is examined using both experimental and physical arguments. Aluminium 2024 alloy is therefore regarded as the reference material that is not reinforced.

A. TENSILE BEHAVIOUR

The tensile characteristics of the prepared composites were measured on a Universal Testing Machine according to the ASTM E8 standards.

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 13, Issue 2, February 2026

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Table 4-1 Experimental Results of Tensile Strength

Sample No	SiC (%)	FA (%)	Tensile Strength (N/mm2)
1	0	0	265
2	2.5	0	266
3	0	2.5	269
4	2.5	2.5	280
5	5	5	290

From the comparison of different samples, it is observed that both SiC and FA contribute to the improvement of the tensile strength of AL2024. However, the combination of both reinforcements gives better results than using only one reinforcement. This is because SiC provides high hardness and strength, while FA helps in better load distribution and particle packing within the matrix.

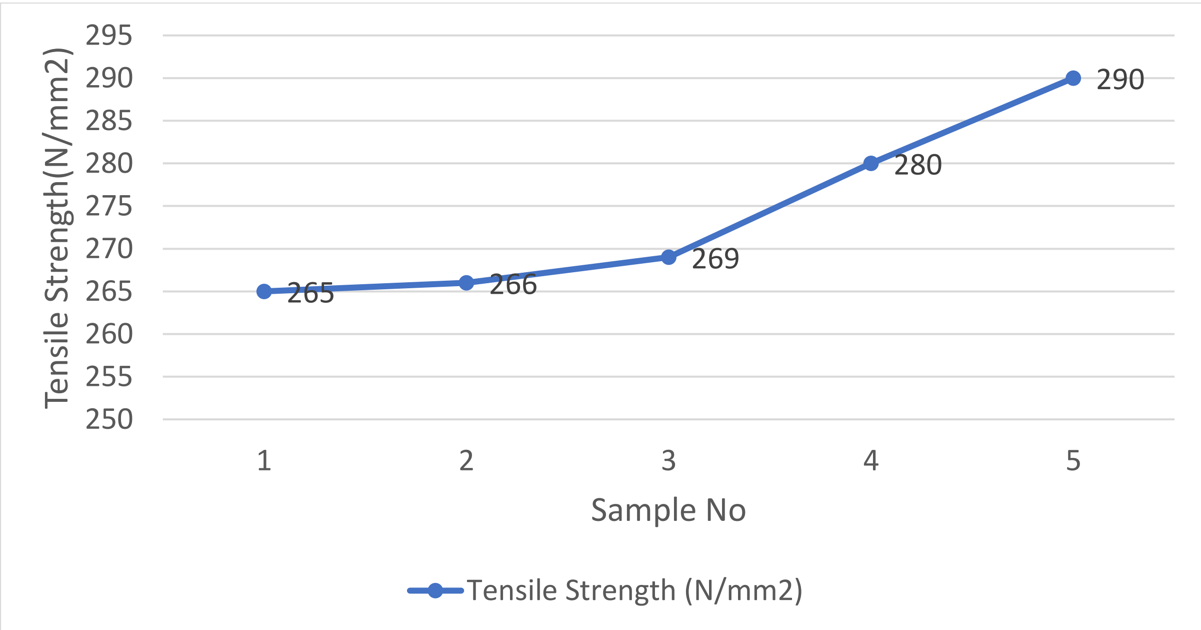

Figure 4-1 Tensile Strength of Samples

International Journal of Advanced Research in Science, Engineering and Technology

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IJARSET IMPACT FACTOR 7.150

Vol. 13, Issue 2, February 2026

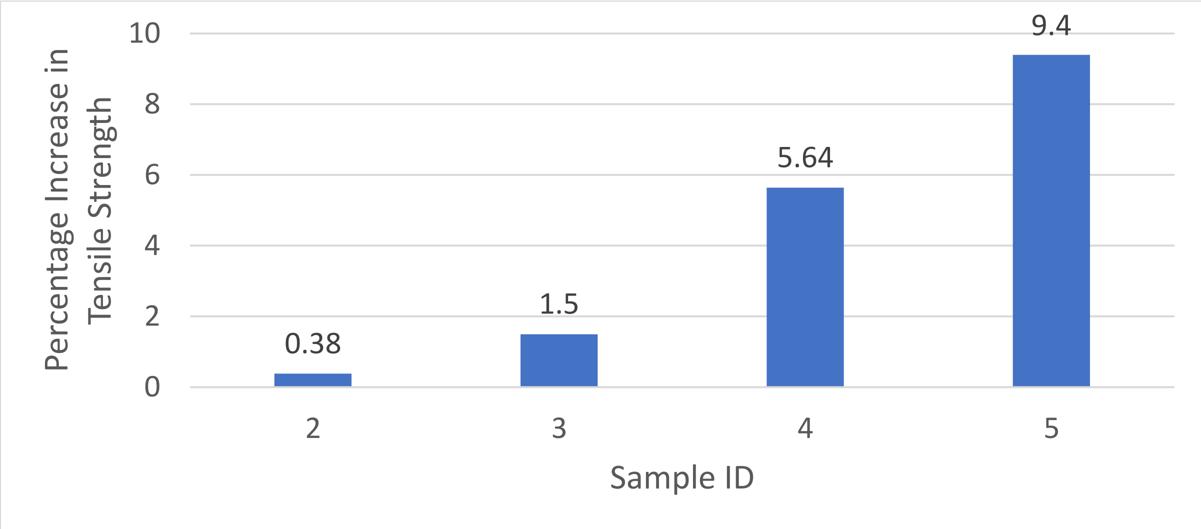

Figure 4-2 Percentage Increase of Tensile Strength

The tensile strength of the unreinforced Aluminium 2024 alloy was the lowest, with 265 N/mm^2. There was a marginal increment when either SiC or fly ash was added individually. It was, however, found that a great deal more tensile strength was attained when both reinforcing materials were used together and this is known as a synergistic effect.

It was found that the maximum tensile strength of 5 wt.% SiC and 5 wt.% FA composite reached 290 N/mm^2. This enhancement can be explained by the fact that the ductile aluminium matrix transfers its loads effectively to the hard reinforcement particles, inhibiting dislocation movement, and enhancing stress distribution as a result of multifaceted packing of the particles.

B. HARDNESS BEHAVIOUR

The measurements of the Brinell hardness of the composites were done in compliance with ASTM E10 standards.

Table 4-2 Experimental Results of Brinell Hardness

Sample No	SiC (%)	FA (%)	Hardness (BHN)
1	0	0	81.67
2	2.5	0	85.93
3	0	2.5	89
4	2.5	2.5	90.27
5	5	5	94.3

The Brinell hardness test results show that the hardness of AL2024 increases with the addition of SiC and FA. Pure AL2024 has the lowest hardness, while the composite containing 5% SiC and 5% FA shows the highest hardness value. This happens because the hard ceramic particles resist indentation and improve the surface resistance of the material.

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Vol. 13, Issue 2, February 2026

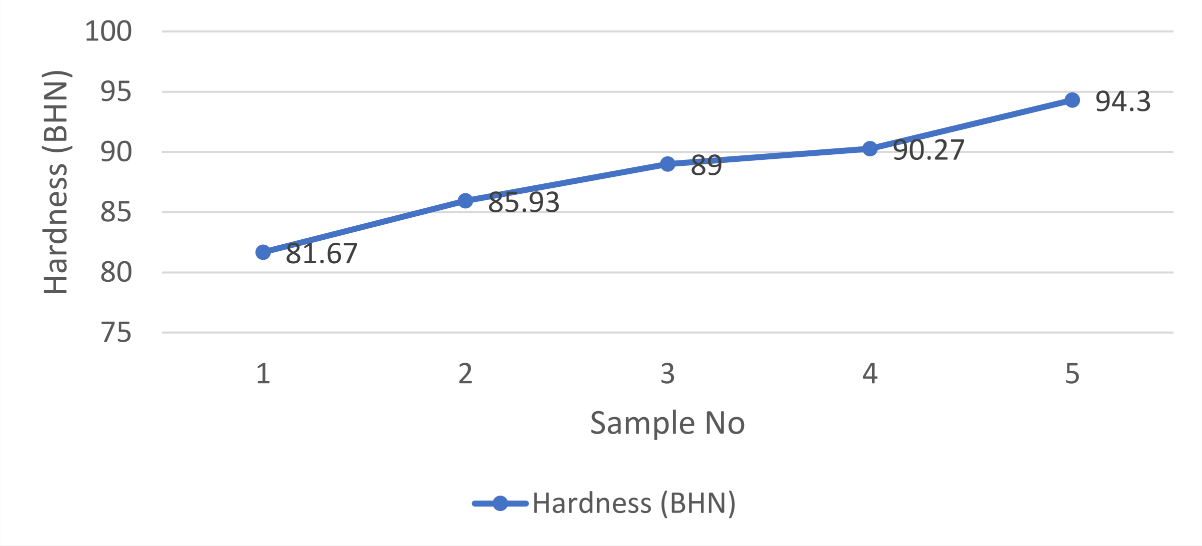

Figure 4-3 Brinell Hardness of samples

The hardness graph shows a steady increase in BHN values as the reinforcement content increases. This indicates that the composite becomes harder and more wear-resistant with the addition of SiC and FA particles. The uniform increase also suggests good bonding between the AL2024 matrix and the reinforcement particles.

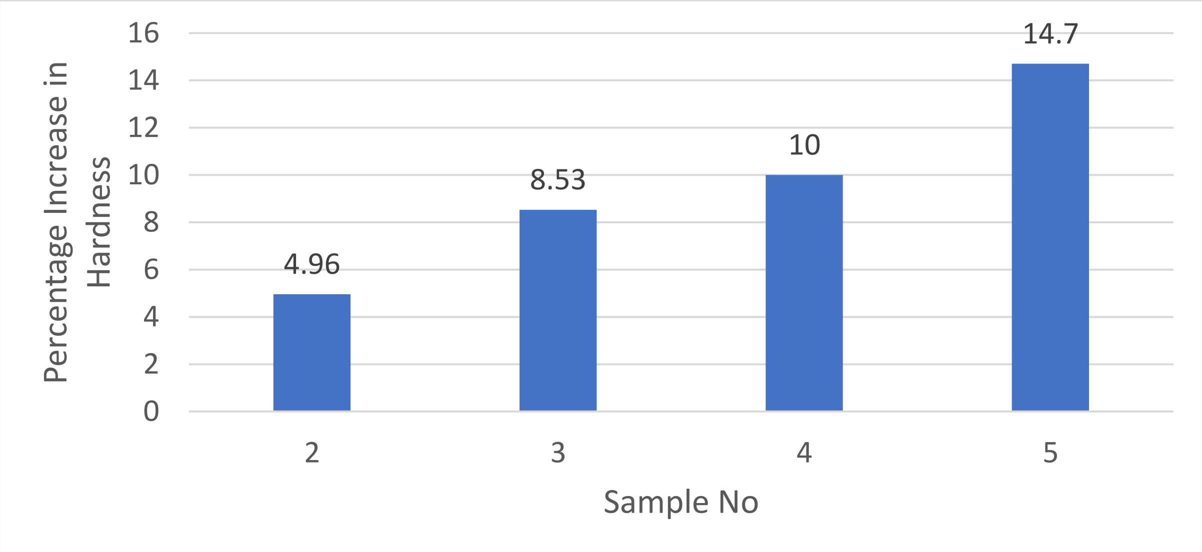

Figure 4-4 Percentage Increase of Brinell Hardness

The distinct increasing tendency of hardness with increasing reinforcement content was found. The Aluminium 2024 alloy, which was not reinforced, had the least hardness of around 81.67 BHN. The high level of intrinsic hardness and resistance to plastic deformation were very important factors that contributed to the increased hardness with the incorporation of SiC. Another role of fly ash was enhancing the hardness through maintaining the rigid filler and refining the structure of the matrix.

The composite reinforced with 5 wt.% silicon carbide and 5 wt.% Ferrous aluminium had the highest hardness of approximately 94.3 BHN. The overall effect of the hard ceramic particle and homogenous dispersion is attributed to this improvement, making it difficult to locally deform under indentation.

C.DENSITY BEHAVIOUR

The measurement of density was conducted through Archimedes' principle to measure the effect of reinforcement addition on the loss of weight.

Table 4-3 Experimental results for density values.

Sample No	SiC (%)	FA (%)	Density (g/cm^3)
1	0	0	2.71
2	2.5	0	2.55
3	0	2.5	2.21
4	2.5	2.5	2.3
5	5	5	2.09

The maximum density of 2.71 g/cm^3 is documented in Sample 1, the unreinforced matrix devoid of both SiC and FA. Conversely, the minimum density, measured at 2.09 g/cm^3, occurs in Sample 5, wherein both reinforcements are present at 5% by weight. This inverse density behaviour aligns with theoretical expectations derived from the density differentials of the constituent phases. This decrease in density and enhanced mechanical properties testify to the efficiency of fly ash as a reinforcing substance for lightweight and justify its application in the creation of sustainable composite.

D.OVERALL DISCUSSION

As shown in the results of the experiment, reinforcement of the Aluminium 2024 with Silicon Carbide and Fly Ash in a hybrid mode gives the same effect of enhancing tensile strength and hardness of the material, and, at the same time, such kind of reinforcement minimizes density of the metal. It is possible to say that the high performance of the 5 wt.% SiC and 5 wt.% FA composite can be explained by the effectiveness of load transfer, lowering the rate of the matrix deformation, and the optimum particle distribution.

Hybrid composites, in comparison to mono-reinforced composites, have a balanced approach in both strength enhancement and reduction of weight, thus suitable to be used especially in aerospace and automotive applications where structural efficiency is key.

V.CONCLUSIONS

The current experimental study tested the mechanical behaviour of hybrid metal matrix composites made of Aluminium 2024 that was reinforced with the use of Silicon Carbide (SiC) and Fly Ash (FA) manufactured through the stir casting method. Due to the results of the experiment and discussions, the following conclusions are made:

1. The stir casting was successful in producing Al2024-SiC-FA hybrid composites with uniform incorporation of reinforcement and excellent interfacial bonding, and this proved the appropriateness of this economical and widely scalable fabrication procedure.
2. Tensile strength of the Aluminium 2024 alloy augmented with reinforcement, and the maximum strength of the composite was found to be about 290 N/mm^2 with the addition of 5 wt.% SiC and 5 wt.% FA, which was quite high compared to the reinforcement-free alloy.
3. The tendency of Brinell hardness to increase with the reinforcement content was the same, as it increased to the highest level of approximately 94 BHN with the reinforcement content of 5 wt. per cent SiC plus 5 wt.per cent FA due to the limitation of plastic deformation by hard ceramic particles.

4. The composite's density reduced significantly with the addition of fly ash, and the lowest density of 2.09 g/cm3 was realised in the highest hybrid reinforcement mixture, which demonstrates the effectiveness of fly ash in reducing the weight of the composites.

The composite reinforced with a combination of SiC and fly ash was observed to be the best overall performer when compared to mono-reinforced composites, and this offers a good balance between an increase in strength and the reduction in density and thus the hybrid composites developed were found to be a viable solution in the lightweight aerospace and automotive industry.

VI.FUTURE SCOPE

1. Even though the current study shows the possibility of Al2024-SiC-FA hybrid composites, it is possible to discuss several future research directions that can be taken to increase their practical value:
2. The tribological behaviour of wear, friction, and erosion under various loads and sliding conditions can be detailed through tribological investigations that can be used to determine the suitability of these composites in moving and contact-based components of the moving machine.
3. To examine long-term anti-corrosion durability and service ability, the behaviour of corrosion in various hostile conditions can be studied, such as marine, acidic, and so on.
4. The heat treatment and ageing studies can be carried out to examine their effects on the development of microstructure and additional advancement of the mechanical properties.
5. The most complex optimisation tools, like Response Surface Methodology (RSM) or Taguchi methods, may help define the best working processing parameters and reinforcement proportions.
6. SEM and EDS microstructural and fractographic analysis can be furthered to create a direct relationship between particle distribution and failure mechanisms and mechanical performance.

REFERENCES

1. Alaneme, K. K., & Aluko, A. O. (2012). Tensile properties and fracture behaviour of silicon carbide particulate reinforced aluminium matrix composites. *Materials & Design*, **37**, 23–31.
2. Rahman, M. H., & Al Rashed, H. M. M. A. (2014). Characterisation of silicon carbide reinforced aluminium matrix composites. *Procedia Engineering*, **90**, 103–109.
3. Rao, J. B., Rao, D. V., & Murthy, I. N. (2012). Fabrication and characterisation of aluminium–fly ash composite using the stir casting method. *Materials Today: Proceedings*, **5**, 298–304.
4. Dinaharan, I., Murugan, N., & Parameswaran, S. (2016). Influence of fly ash content on microstructure and mechanical properties of AA6061/fly ash composites fabricated using friction stir processing. *Materials Science and Engineering A*, **659**, 182–192.
5. Kountouras, D. T., Stergioudi, F., & Pavlidou, E. (2015). Microstructural characterisation and corrosion behaviour of aluminium–fly ash composites. *Journal of Alloys and Compounds*, **640**, 184–193.
6. Ravesh, S., & Garg, T. K. (2012). Preparation & analysis of properties of aluminium–silicon carbide–fly ash hybrid composites. *International Journal of Engineering Research and Applications*, **2**(4), 727–731.
7. Mahendra Boopathi, M., Arulshri, K. P., & Iyandurai, N. (2013). Evaluation of mechanical properties of aluminium alloy 2024 reinforced with silicon carbide and fly ash hybrid metal matrix composites. *American Journal of Applied Sciences*, **10**(3), 219–229.
8. Dwivedi, S. P., Sharma, S., & Mishra, R. K. (2014). Microstructure and mechanical behaviour of A356/SiC/fly ash hybrid composites produced by electromagnetic stir casting. *Materials Science and Engineering A*, **600**, 1–10.
9. Kurapati, S., & Kommineni, R. (2017). Dry sliding wear behaviour of aluminium 2024 hybrid metal matrix composites reinforced with fly ash and silicon carbide. *Tribology in Industry*, **39**(2), 193–201.
10. Kurapati, S., Kommineni, R., & Reddy, P. R. (2018). Optimisation of wear parameters of Al2024–SiC–fly ash composites using the Taguchi method. *Materials Today: Proceedings*, **5**, 24210–24217.
11. Mohanavel, V., Ravichandran, M., & Prabu, S. S. (2018). Mechanical and tribological behaviour of AA6351–SiC composites fabricated by stir casting. *Journal of Materials Research and Technology*, **7**(4), 444–453.
12. Kumar, S., Singh, J., & Chauhan, A. (2020). Microstructural and mechanical characterisation of Al2024–SiC–fly ash hybrid composites. *Materials Today: Proceedings*, **26**, 3003–3008.
13. Prem Kumar, K., Prasad, N. E., & Ramachandra, M. (2019). Processing and characterisation of aluminium-based metal matrix composites by the stir casting technique. *Journal of Materials Engineering and Performance*, **28**, 502–512.
14. Reddy, M. P., & Srinivas, C. (2018). Fabrication and mechanical characterisation of aluminium hybrid composites reinforced with SiC and fly ash. *Journal of Composite Materials*, **52**(20), 2793–2805.
15. Zhang, L., Wang, J., & Chen, G. (2019). Recent advances in aluminium matrix composites reinforced with ceramic particles. *Journal of Materials Science*, **54**, 103–125.