Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 2 (2024)

Influence of SiC Reinforcement on Mechanical Properties of AA2024 Metal Matrix Composites (AMMC) Fabricated via Stir Casting Method: A Review

[1]R. A. Oza, [2]Anand B. Dhruv

[1]*Research Scholar, Gujarat Technological University, Ahmedabad, 382424, Gujarat, India*

[2]*Profesor, Department of Mechanical Engineering, Government Engineering College, Patan, 384265, Gujarat, India*

Abstract:- This research explores into the impact of different reinforcements on the mechanical properties of AA2024 Metal Matrix Composites (MMCs). Specifically, it meticulously investigates the effect of varying weight percentages (wt%) of Silicon Carbide (SiC) on the mechanical characteristics of AA2024 MMCs. The study employs the stir casting technique, a widely recognized method in composite fabrication, to meticulously integrate SiC particles into the AA2024 aluminum matrix. Stir casting ensures the homogeneous dispersion of the reinforcements throughout the aluminum matrix, thereby enhancing the structural integrity and mechanical properties of the resulting composites. The findings derived from this study hold significant implications for the optimization of AA2024 MMCs in various engineering applications. By exposing the intricate relationship between reinforcement type, weight percentage, and mechanical properties, this research contributes to the development of tailored MMCs with enhanced performance characteristics. These insights are poised to guide future endeavors in the design and fabrication of MMCs, facilitating advancements in lightweight, high-strength materials for diverse industrial applications.

Keywords: *Stir Casting, AA2024 –SiC Composite, Reinforcement.*

1. Introduction

Stir casting is a widely utilized manufacturing process in the field of metal matrix composites (MMCs), offering a versatile method for producing materials with tailored properties to meet specific engineering requirements. This process involves the incorporation of reinforcing materials, such as particles or fibers, into a molten metal matrix, resulting in a composite material with enhanced mechanical and physical properties compared to the base metal alone. The stirring action, typically achieved through the use of a rotating impeller or rod, facilitates the dispersion and distribution of the reinforcing phase within the molten metal, ensuring uniformity and homogeneity in the final composite structure [1].

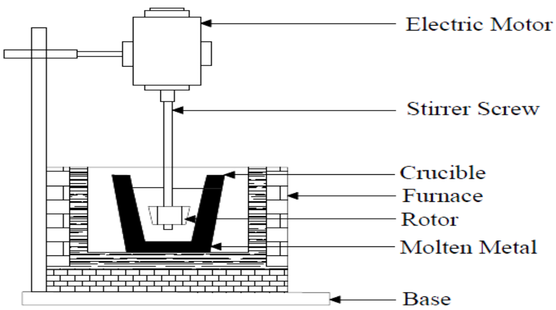


Fig. 1 Stir casting process to fabricate MMC [1]

Aluminum and its alloys need to possess outstanding characteristics to meet the current requirement for lightweight structures with exceptional qualities. To achieve these qualities, such as superior strength and resistance to wear, one approach is using aluminum matrix composites (AMCs) containing ceramic reinforcements. [2]. Several methods have been reported for producing these materials, such as casting and powder metallurgy[3], each with its own limitations. For instance, powder metallurgy processes tend to be costly [4]. Conversely, while casting is simpler and more economical, it presents issues like poor wettability of ceramic particles with the matrix material [5]. Part of the solution to this problem is to apply a metal coating to the ceramic particles [6]. Nevertheless, the mechanical characteristics of the composite are reduced by the brittle reactive products that develop at the interface between the reinforcement and the matrix [7]. Creating reinforcement inside the aluminum matrix using in-situ methods is an other way to address this problem. Compared to the previous process, this one produces a clean, flawless interface since the reactive products are thermodynamically stable. However, the main disadvantage of this approach is that it needs high temperatures to start the reactions [8]. An other technique is called reactive infiltration, in which metal particles combine with the aluminum matrix to create intermetallic reinforcing particles like Al3Ti. But one disadvantage of these methods is that they need specific equipment and high temperatures to create the AMCs [9]. Adding metal particles while stirring molten aluminum is one method that has been investigated recently by a number of researchers. Based on their solubility in aluminum, metal particles are typically divided into two groups: low-solubility metals like nickel, titanium, and tungsten, and high-solubility metals like zinc [10]. The first group's greater strength and stiffness over aluminum make it a known reinforcing element in aluminum matrix composites.

Few research have looked on the casting techniques for creating metal-based reinforced aluminum matrix composites. The A356 composite reinforced with copper particles outperformed the unreinforced A356 alloy in terms of hardness, ductility, yield strength, and elastic modulus. [11]. The influence of different weight percentages of copper on the mechanical properties of stir-cast Al-Cu(p) composite was investigated by Madhusudan et al. [12]. They discovered that adding copper in the 5–10 wt% range improved strength, while adding more than 15 wt% resulted in strength loss because to particle aggregation. Furthermore, higher hardness and a more homogeneous microstructure were produced by increasing copper concentration. In comparison to the unreinforced AA6061 alloy, Rahman and Jayahari[13] observed better mechanical characteristics and wear resistance in the AA6061 matrix composite due to the incorporation of steel chips employing stir casting. that various authors have conducted research on stir casting using different grades of aluminium. However, among these different grades, AA2024 stands out due to its superior properties in particular application. The study investigates the impact of incorporating varying weights of silicon carbide powder in the AA2024 processing thorugh stir casting method.

2. Effect of Different Reinforcement on Mechanical Properties of AA2024 MMC

The 2XXX series of aluminum alloys stands out as a pinnacle of strength within the aluminum alloy spectrum. Renowned for its exceptional mechanical properties, this alloy boasts a remarkable combination of attributes that make it highly desirable for various applications [14]. With a tensile strength ranging from 160 to 200 MPa, it stands as a testament to its formidable strength, making it suitable for applications demanding resilience and structural integrity. Moreover, its hardness ranging between 90 to 100 HV underscores its robustness and resistance to deformation under load. However, strength is not its only forte; the AA2024 also exhibits excellent machining characteristics, facilitating ease of fabrication and shaping processes [15]. Furthermore, its fatigue resistance ensures prolonged durability, making it ideal for components subjected to cyclic loading. Table 1 shows the chemical composition of AA2024. Despite these commendable traits, it's important to acknowledge its lower tribological properties, indicating a propensity for increased wear and friction in certain applications. Nonetheless, the 2XXX aluminum alloy remains an indispensable choice in engineering scenarios where strength, machinability, and fatigue resistance are paramount.

Table 1: Chemical composition of AA2024 alloy

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
%	0.22	0.18	3.90	0.44	1.38	0.011	0.05	0.016	Bal.

Several reinforcements are used in stir casting for aluminum metal matrix composites (AMMCs) in order to improve the materials' mechanical, thermal, and wear characteristics. One commonly used reinforcement is silicon carbide (SiC), known for its high strength and stiffness, which significantly improves the tensile and wear resistance of the composite [16]. Another popular choice is alumina (Al_2O_3) due to its high hardness and thermal stability, making it effective in enhancing the wear resistance and thermal conductivity of the AMMC [17]. Additionally, graphite (Gr) is utilized for its lubricating properties, aiding in the reduction of friction and wear [18]. Boron fibers offer exceptional strength and stiffness, contributing to improved mechanical properties such as tensile strength and modulus of elasticity [19]. Other reinforcements like fly ash and molybdenum disulfide (MoS_2) are also utilized, providing benefits such as cost-effectiveness and enhanced lubrication, respectively [20]. Each reinforcement brings unique characteristics to the composite, and their selection depends on the desired properties and intended applications of the final material. Through careful consideration and optimization of reinforcement materials, stir casting for AMMCs continues to advance, offering tailored solutions for a wide range of industrial and engineering applications. Table 2 shows the different reinforcements commonly used in stir casting for aluminum metal matrix composites (AMMCs), along with their properties and applications.

Table 2: Different reinforcements with their properties and applications

Reinforcement	Salient properties	Applications
Al_2O_3	High strength to weight ratio High hardness	Brake discs, pistons, cylinder heads, connecting rods
SiC	Low cost, availability, high strength, hardness, stiffness, corrosion resistance, wear resistance and excellent thermal conductivity	Pistons, brake rotors, calipers, liners, propeller shaft, connecting rod, brake rotors, driveshaft, engine cradle and Automotive applications
B_4C	High strength, low density, high hardness, excellent chemical stability, and neutron absorption capability	Automotive applications
Fly ash	Lower cost, high tensile strength, compressive strength, impact strength, and hardness	Covers, pans, shrouds, casings, pulleys, manifolds, valve covers, brake rotors, and engine blocks in automobiles
CNT	High strength-to-weight ratio, low density, increase in yield strength, tensile strength, ductility, and hardness	Brake shoes, cylinder liners and aircraft landing gears
TiO_2	Strong bonding, high tensile strength, hardness and impact strength	Automobile applications

Fig. 2 presented illustrates the significant potential for enhancing hardness through various combinations of materials. Among these combinations, those involving fly ash, SiC, boron nitride, Gr (graphene), B_4C, and Al_2O_3 exhibit notable improvements in hardness values[21][22][23][24][25][26][27][28][29]. Notably, fly ash emerges as a particularly effective component, both independently and in combination with other materials such as SiC and fly-ash. These findings underscore the importance of exploring composite materials and their synergistic effects in advancing hardness properties, offering valuable insights for applications across diverse industries ranging from construction to manufacturing. Further research in this direction holds promise for unlocking even greater advancements in material science and engineering.

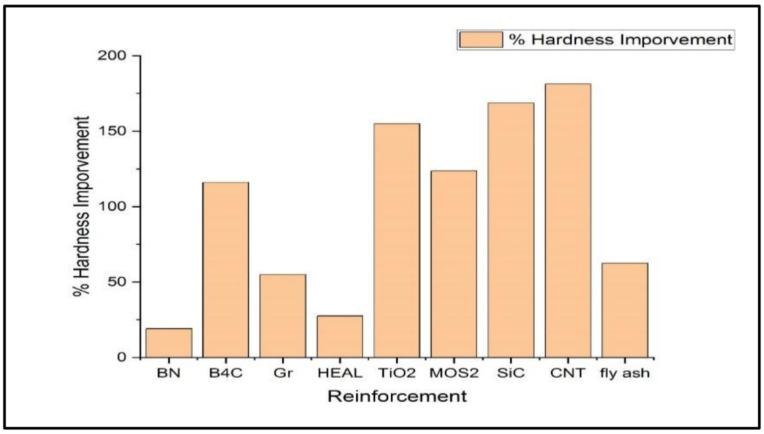


Figure 2: % Hardness Improvement observed with different reinforcement

The potential of different materials to improve tensile strength in relation to AA2024 is shown in Fig. 3. [23][24][25][26][27][28][29]. Among these materials, TiO_2, Al_2O_3, and fly ash demonstrate substantial improvements, surpassing the tensile strength of AA2024 by significant margins. Notably, the combination of fly ash and SiC exhibits an impressive enhancement in tensile strength, indicating the synergistic effects of composite materials. Additionally, HEAL (High-Entropy Alloy) emerges as a promising candidate for boosting tensile strength. These findings underscore the importance of exploring diverse material compositions and their interactions to advance the mechanical properties of alloys. Further research in this area holds promise for developing high-performance materials with enhanced tensile strength, benefiting a wide range of applications in aerospace, automotive, and structural engineering industries.

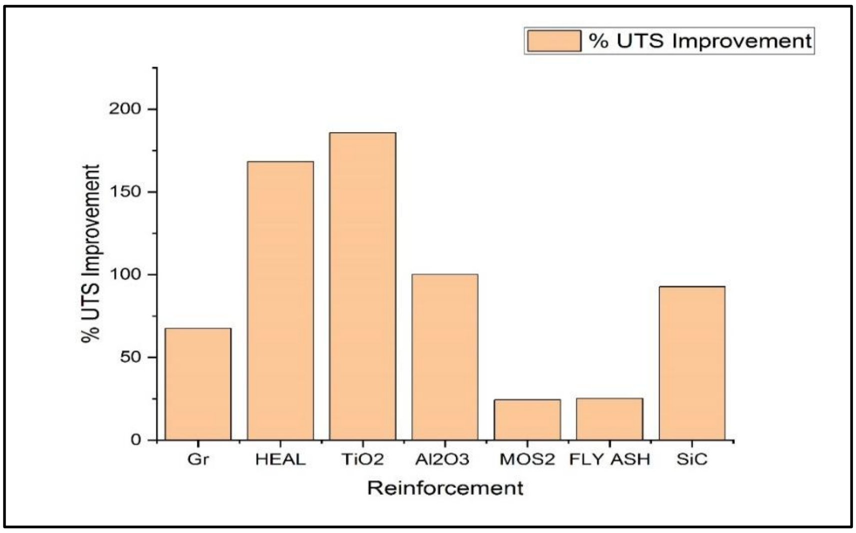


Figure 3: % Tensile strength improvement observed with different reinforcement

Overall, the combination of high strength, stiffness, thermal stability, wear resistance, corrosion resistance, lightweight nature, and cost-effectiveness makes SiC a widely used reinforcement material with AA2024 alloy and other metal matrices. SiC-reinforced AA2024 alloy composites are used in the manufacturing of flight control hydraulic manifolds in aircraft[30]. These manifolds require materials with high strength, stiffness, and resistance to wear and corrosion, making SiC-reinforced composites an ideal choice. The braking system of Lotus Elise, an agile and lightweight sports car, could benefit from the use of SiC-reinforced AA2024 alloy composites in brake discs[31]. Similarly, in electric vehicles like GM EV1, Chrysler Prowler, Volkswagen Lupo 3L, and Toyota RAV4 EV, where weight reduction and high performance are crucial, SiC-reinforced composites can be utilized in brake discs to enhance braking efficiency and reduce energy consumption[14].

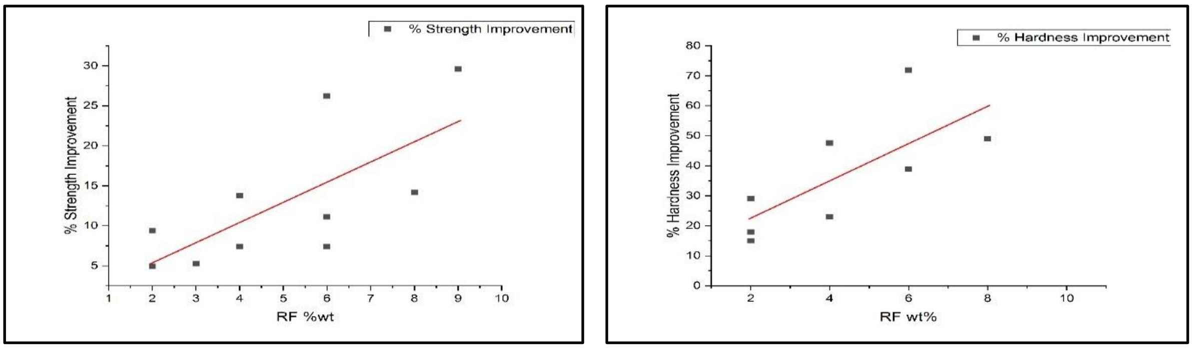
3. Effect of wt% of SiC on Mechanical Properties of AA2024 MMC

The weight percentage (wt%) of silicon carbide (SiC) in the AA2024 metal matrix composite (MMC) significantly influences its mechanical properties. Table 3 shows the mechanical properties of AA2024 and SiC [32]. Here's a general overview of how the wt% of SiC affects various mechanical properties of AA2024 MMC:

Table 3: Mechnical properties of AA2024 and SiC [32]

Properties	Matrix Material AA2024	Reinforcement SiC
Melting Point	600 °C	2830 °C
Density	2.78 g/cc	3.21 g/cc
Tensile Strength	185 MPa	310 MPa
Flexural Strength	237 Mpa	324 Mpa
Young's Modulus	70-80 GPa	4.8 GPa
Thermal Conductivity	193 W/mk	41 W/mk

Tensile Strength: Increasing the wt% of SiC generally leads to an increase in the tensile strength of the composite as shown in Figure 4(a). This is because SiC particles act as strengthening agents within the matrix, hindering dislocation movement and providing resistance to deformation [27][33][34].



(a) (b)

Figure 4: % Strength and Hardness improvement with varying the SiC wt%

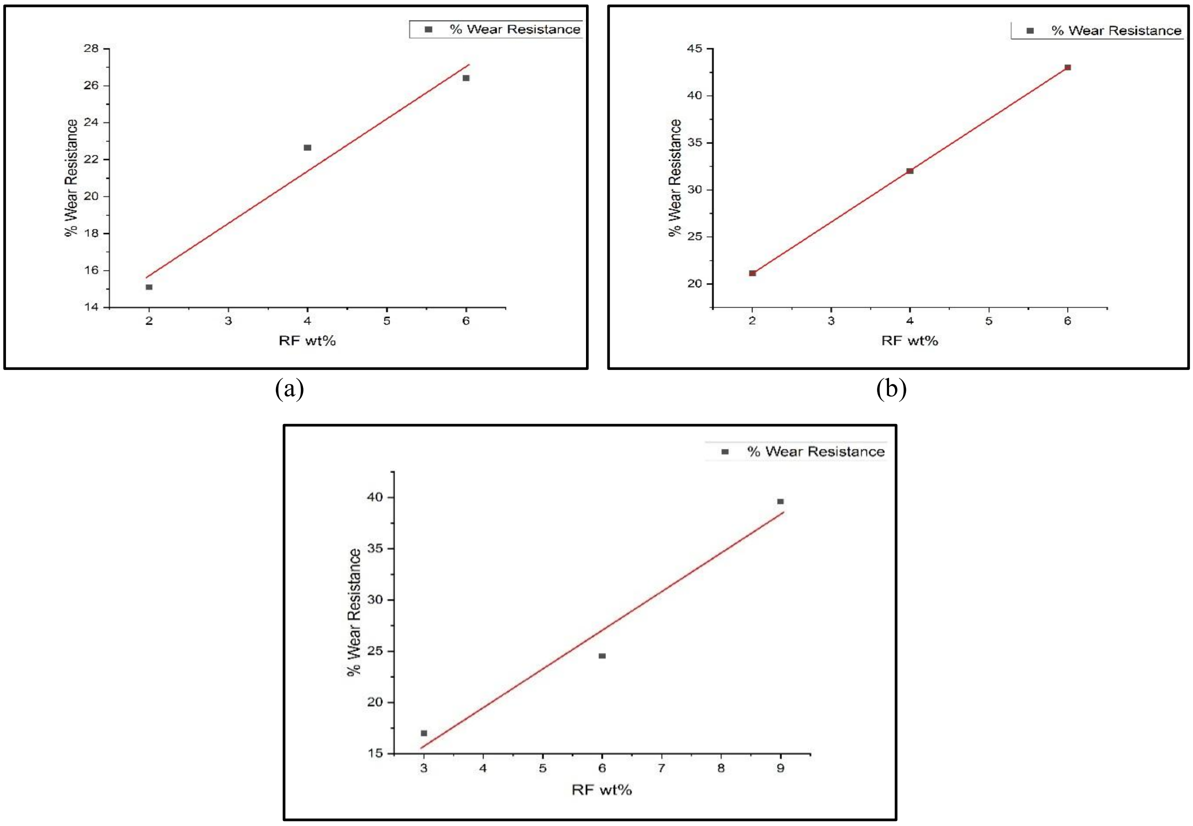
Yield Strength: Similar to tensile strength, the yield strength of AA2024 MMC tends to increase with higher wt% of SiC. The presence of SiC particles effectively strengthens the material, leading to higher resistance to plastic deformation.

Hardness: The addition of SiC particles typically results in increased hardness of the composite as shown in Fig. 4(b). SiC is a hard material, and as its wt% increases, it contributes to the overall hardness of the composite, making it more resistant to indentation and wear[27][33][34].

Fracture Toughness: The fracture toughness of AA2024 MMC may show some variation with changes in the wt% of SiC. In general, higher wt% of SiC can enhance the fracture toughness by promoting crack deflection and energy absorption mechanisms, thereby increasing the material's resistance to crack propagation.

Fatigue Strength: The effect of SiC wt% on fatigue strength can vary depending on factors such as particle distribution, size, and matrix material. In some cases, increasing SiC content can improve fatigue strength by reducing the initiation and propagation of fatigue cracks, while in others, it may lead to a reduction due to stress concentration effects.

Wear Resistance: Higher wt% of SiC typically results in improved wear resistance of AA2024 MMC as shown in Fig.5. SiC particles, being hard and wear-resistant, can reduce material loss due to sliding or abrasive wear, thereby enhancing the overall wear performance of the composite.[35][36][37]



(a) (b)

(c)

Figure 5: %Wear Resistance Improvement with varying the SiC wt%

4. Conclusion

This research has illuminated the profound impact of different reinforcement materials on the mechanical properties of AA2024 Metal Matrix Composites (MMC). We have discerned that the choice of reinforcement profoundly influences the mechanical behavior of the composite material. Each reinforcement material exhibits unique characteristics, which directly translate into variations in strength, stiffness, toughness, and other mechanical properties of the composite. These findings underscore the significance of judiciously selecting reinforcement materials based on the desired performance criteria for specific applications. Furthermore, this study highlights the effectiveness of the stir-casting process for the fabrication of AA2024-SiC composites with tailored properties. The optimized fabrication parameters and enhanced mechanical performance pave the way for the utilization of these composites in aerospace, automotive, and other high-performance applications.

Refrences

[1] R. A. Oza and P. H. Shah, "A Review of Friction Stir Processing (FSP) on Stir Cast Aluminum Based Composites," vol. 21, no. 9, pp. 1343–1361.

[2] D. Brough and H. Jouhara, "The aluminium industry: A review on state-of-the-art technologies, environmental impacts and possibilities for waste heat recovery," Int. J. Thermofluids, vol. 1–2, p. 100007, Feb. 2020, doi: 10.1016/j.ijft.2019.100007.

[3] P. Garg, A. Jamwal, D. Kumar, K. K. Sadasivuni, C. M. Hussain, and P. Gupta, "Advance research progresses in aluminium matrix composites: manufacturing & applications," J. Mater. Res. Technol., vol. 8, no. 5, pp. 4924–4939, Sep. 2019, doi: 10.1016/j.jmrt.2019.06.028.

[4] Z. Z. Fang et al., “Powder metallurgy of titanium – past, present, and future,” Int. Mater. Rev., vol. 63, no. 7, pp. 407–459, Oct. 2018, doi: 10.1080/09506608.2017.1366003.
[5] A. Kumar Sharma, R. Bhandari, A. Aherwar, and C. Pinca-Bretotean, “A study of fabrication methods of aluminum based composites focused on stir casting process,” Mater. Today Proc., vol. 27, pp. 1608–1612, 2020, doi: 10.1016/j.matpr.2020.03.316.
[6] S. S. Murugan and T. P. D. Rajan, “Characterization of Graphite-Reinforced LM30-Aluminium Matrix Composite Processed through Gravity and Vertical Centrifugal Casting Processes,” J. Inst. Eng. Ser. D, vol. 102, no. 1, pp. 19–26, 2021, doi: 10.1007/s40033-020-00242-1.
[7] V. M. Bermudez, “Auger and electron energy-loss study of the Al/SiC interface,” Appl. Phys. Lett., vol. 42, no. 1, pp. 70–72, Jan. 1983, doi: 10.1063/1.93730.
[8] J. M. Mistry and P. P. Gohil, “Research review of diversified reinforcement on aluminum metal matrix composites: fabrication processes and mechanical characterization,” Sci. Eng. Compos. Mater., vol. 25, no. 4, pp. 633–647, Jul. 2018, doi: 10.1515/secm-2016-0278.
[9] E. Louis, J. A. Miralles, and J. M. Molina, “Reactive infiltration: identifying the role of chemical reactions, capillarity, viscosity and gravity,” J. Mater. Sci., vol. 52, no. 12, pp. 7530–7538, Jun. 2017, doi: 10.1007/s10853-017-0985-x.
[10] G. Kiourtsidis and S. M. Skolianos, “Corrosion behavior of squeeze-cast silicon carbide-2024 composites in aerated 3.5 wt.% sodium chloride,” 1998.
[11] Gopi Krishna, K. Praveen Kumar, M. Naga Swapna, J. Babu Rao, and N. R. M. R. Bhargava, “Fabrication, Characterization and Mechanical Behaviour of A356/ Copper Particulate Reinforced Metallic Composites,” Mater. Today Proc., vol. 5, no. 2, pp. 7685–7691, 2018, doi: 10.1016/j.matpr.2017.11.444.
[12] S. Madhusudan, M. M. M. Sarcar, and N. B. R. M. Rao, “Mechanical properties of Aluminum-Copper(p) composite metallic materials,” J. Appl. Res. Technol., vol. 14, no. 5, pp. 293–299, Oct. 2016, doi: 10.1016/j.jart.2016.05.009.
[13] M. S. U. Rahman and L. Jayahari, “Study Of Mechanical Properties and Wear Behaviour of Aluminium 6061 Matrix Composites Reinforced with Steel Machining Chips,” Mater. Today Proc., vol. 5, no. 9, pp. 20117–20123, 2018, doi: 10.1016/j.matpr.2018.06.379.
[14] M. Kumar and A. Kumar, “Application of preference selection index method in performance based ranking of ceramic particulate (SiO2/SiC) reinforced AA2024 composite materials,” in Materials Today: Proceedings, 2019, vol. 27, pp. 2667–2672. doi: 10.1016/j.matpr.2019.11.244.
[15] B. Rebba and N. Ramanaiah, “Evaluation of Mechanical Properties of Aluminium Alloy (Al-2024) Reinforced with Molybdenum Disulphide (MOS_2) Metal Matrix Composites,” Procedia Mater. Sci., vol. 6, pp. 1161–1169, 2014, doi: 10.1016/j.mspro.2014.07.189.
[16] S. Bhaskar, M. Kumar, and A. Patnaik, “Silicon Carbide Ceramic Particulate Reinforced AA2024 Alloy Composite - Part I: Evaluation of Mechanical and Sliding Tribology Performance,” Silicon, vol. 12, no. 4, pp. 843–865, Apr. 2020, doi: 10.1007/s12633-019-00181-x.
[17] H. I. Akbar, E. Surojo, D. Ariawan, G. A. Putra, and R. T. Wibowo, “Effect of reinforcement material on properties of manufactured aluminum matrix composite using stir casting route,” Procedia Struct. Integr., vol. 27, no. 2019, pp. 62–68, 2020, doi: 10.1016/j.prostr.2020.07.009.
[18] L. Natrayan, S. Yogeshwaran, L. Yuvaraj, and M. S. Kumar, “Effect of graphene reinforcement on mechanical and microstructure behavior of AA8030/graphene composites fabricated by stir casting technique,” 2019, p. 020012. doi: 10.1063/1.5131599.
[19] H. S. Kumaraswamy, V. Bharat, and T. K. Rao, “Influence of Boron Fiber Powder and Graphite Reinforcements on Physical and Mechanical Properties of Aluminum 2024 Alloy Fabricated by Stir Casting,” J. Miner. Mater. Charact. Eng., vol. 07, no. 03, pp. 103–116, 2019, doi: 10.4236/jmmce.2019.73008.
[20] A. Kumar, R. C. Singh, R. Chaudhary, and V. P. Singh, “Tribological studies and Microstructural characterisation of SiC and Fly Ash Particles Based Aluminium 2024 alloy Composites Prepared through Stir Casting Route,” in IOP Conference Series: Materials Science and Engineering, Jun. 2020, vol. 804, no. 1. doi: 10.1088/1757-899X/804/1/012025.

[21] F. Aydın, “Investigation of Elevated Temperature Wear Behavior of Al 2024-BN Composites using Statistical Techniques,” J. Mater. Eng. Perform., vol. 30, no. 11, pp. 8560–8578, Nov. 2021, doi: 10.1007/s11665-021-06011-9.
[22] K. Sunil, R. Kumar, C. Ratnam, B. Nagababu, and A. Professor, “ScienceDirect Fabrication and Mechanical Behavior of Al 2024-B 4 C MMCs And Al 2024-B 4 C-Gr Hybrid Mmcs through Powder Metallurgy Technique,” 2019. [Online]. Available: www.sciencedirect.com
[23] M. Anthony Xavior, N. Ranganathan, and P. H. Kumar, “Mechanical properties evaluation of hot extruded AA 2024-Graphene Nanocomposites,” 2018. [Online]. Available: www.sciencedirect.comwww.materialstoday.com/proceedings2214-7853
[24] O. Ertugrul, T. He, R. N. Shahid, and S. Scudino, “Effect of heat treatment on microstructure and mechanical properties of Al 2024 matrix composites reinforced with Ni60Nb40 metallic glass particles,” J. Alloys Compd., vol. 808, Nov. 2019, doi: 10.1016/j.jallcom.2019.151732.
[25] J. H. Shin, H. J. Choi, and D. H. Bae, “The structure and properties of 2024 aluminum composites reinforced with TiO_2 nanoparticles,” Mater. Sci. Eng. A, vol. 607, pp. 605–610, Aug. 2014, doi: 10.1016/j.msea.2014.04.038.
[26] M. Mahendra Boopathi, K. P. Arulshri, and N. Iyandurai, “Evaluation of mechanical properties of Aluminium alloy 2024 reinforced with silicon carbide and fly ash hybrid metal matrix composites,” Am. J. Appl. Sci., vol. 10, no. 3, pp. 219–229, Apr. 2013, doi: 10.3844/ajassp.2013.219.229.
[27] H. M. Zakaria, “Microstructural and corrosion behavior of Al/SiC metal matrix composites,” Ain Shams Eng. J., vol. 5, no. 3, pp. 831–838, 2014, doi: 10.1016/j.asej.2014.03.003.
[28] R. Pérez-Bustamante, F. Pérez-Bustamante, I. Estrada-Guel, L. Licea-Jiménez, M. Miki-Yoshida, and R. Martínez-Sánchez, “Effect of milling time and CNT concentration on hardness of CNT/Al2024 composites produced by mechanical alloying,” Mater. Charact., vol. 75, pp. 13–19, Jan. 1970, doi: 10.1016/j.matchar.2012.09.005.
[29] J. B. Rao, D. V. Rao, I. N. Murthy, and N. Bhargava, “Mechanical properties and corrosion behaviour of fly ash particles reinforced AA 2024 composites,” J. Compos. Mater., vol. 46, no. 12, pp. 1393–1404, Jun. 2012, doi: 10.1177/0021998311419876.
[30] P. Rambabu, N. E. Prasad, and V. V Kutumbarao, “Aluminium Alloys for Aerospace Applications,” 2017, doi: 10.1007/978-981-10-2134-3.
[31] F. Nturanabo, L. Masu, and J. B. Kirabira, “Novel Applications of Aluminium Metal Matrix Composites”.
[32] Z. Feng, C. Lin, J. Lin, and J. Luo, “Pitting behavior of SiCp/2024 Al metal matrix composites,” 1998.
[33] Y. Ma, Y. N. Liang, Y. Z. Zhang, Y. X. Lu, and J. Bi, “Sliding \Near behaviour of SiC particle reinforced 2024 alul11iniul11alloy cOl11posites z,” 1996.
[34] S.-J. Hong, H.-M. Kim, D. Huh, C. Suryanarayana, and B. S. Chun, “Effect of clustering on the mechanical properties of SiC particulate-reinforced aluminum alloy 2024 metal matrix composites.” [Online]. Available: www.elsevier.com/locate/msea
[35] D. Dey, S. K. Chintada, A. Bhowmik, and A. Biswas, “Evaluation of wear performance of Al2024-SiC ex-situ composites,” in Materials Today: Proceedings, 2019, vol. 26, pp. 2996–2999. doi: 10.1016/j.matpr.2020.02.619.
[36] D. Dey, A. Bhowmik, and A. Biswas, “Effect of SiC Content on Mechanical and Tribological Properties of Al2024-SiC Composites,” Silicon, vol. 14, no. 1, Jan. 2022, doi: 10.1007/s12633-020-00757-y.
[37] S. Bhaskar, M. Kumar, and A. Patnaik, “Microstructure, Thermal, Thermo-mechanical and Fracture Analyses of Hybrid AA2024-SiC Alloy Composites,” Trans. Indian Inst. Met., vol. 73, no. 1, pp. 181–190, Jan. 2020, doi: 10.1007/s12666-019-01819-5.