2026 Volume: 02 Issue: 06 www.ijrpa.com ISSN 2456-9995 Review Article

International Journal Research Publication Analysis

Page: 01-14

TRIBOLOGICAL PERFORMANCE OF TIN-BASED BABBITT COMPOSITE MATERIALS: A REVIEW

***Prof. Bhushan Karamkar, Shraddha G. Biradar, Masoud A. Tambu, Ketan P. Gavali, Darshan U. Gopale**

Mechanical Engineering Dept, DPCOE, Pune.

Article Received: 7 May 2026
Article Revised: 27 May 2026
Published on: 17 June 2026

***Corresponding Author: Prof. Bhushan Karamkar**
Mechanical Engineering Dept, DPCOE, Pune.

DOI: https://doi-doi.org/101555/ijrpa.4170

ABSTRACT

Tin-based Babbitt alloys are widely employed as bearing materials in automotive, marine, aerospace, and industrial machinery due to their excellent conformability, embeddability, fatigue resistance, and anti-seizure properties. However, increasing demands for higher load-carrying capacity, enhanced wear resistance, and improved frictional performance have led researchers to develop tin-based Babbitt composite materials reinforced with ceramic particles, solid lubricants, and nano-fillers. This review presents a comprehensive analysis of the tribological performance of tin-based Babbitt composites. The influence of reinforcement materials, manufacturing techniques, wear mechanisms, friction characteristics, microstructural evolution, and operating conditions on tribological behavior is discussed. Recent advancements in nano-reinforced Babbitt composites and future research directions are also highlighted. The review demonstrates that composite reinforcements significantly improve wear resistance and reduce friction while maintaining the desirable bearing characteristics of conventional Babbitt alloys.

KEYWORDS: Tin-based Babbitt, Tribology, Composite Materials, Wear Resistance, Friction Coefficient, Bearing Materials, Nano-Reinforcement.

1. INTRODUCTION

Tribology is the science of friction, wear, and lubrication between interacting surfaces in relative motion. Bearings are critical machine elements that support rotating shafts and reduce frictional losses. Among various bearing materials, tin-based Babbitt alloys have been extensively used for over a century because of their unique combination of mechanical and tribological properties.

Table: Element Composition.

Element	Composition
Tin(Sn)	80-90
Antimony(Sb)	5-15
Copper(Cu)	3-8

The graph illustrates the comparative wear performance of pure tin-based Babbitt alloy and various reinforced Babbitt composite materials. The wear rate values are presented in relative units, where a lower value indicates better wear resistance and superior tribological performance.

The results show that Pure Babbitt exhibits the highest wear rate of 100, indicating the lowest resistance to wear under sliding conditions. This is primarily due to the relatively soft tin-rich matrix, which undergoes greater material removal during frictional contact.

The incorporation of Al_2O_3 (Aluminum Oxide) particles reduces the wear rate to approximately 75, representing a significant improvement in wear resistance. The hard ceramic particles act as load-bearing elements and minimize direct surface deformation.

Similarly, the SiC (Silicon Carbide) reinforced composite demonstrates a wear rate of approximately 65, which is lower than that of the Al_2O_3 composite. The superior hardness of SiC particles enhances abrasion resistance and reduces material loss during sliding.

The Graphite reinforced composite exhibits a wear rate of around 70. Although its wear resistance is slightly lower than that of the SiC composite, graphite contributes to friction reduction through the formation of a lubricating film on the contact surface. This self-lubricating property improves the overall tribological behavior of the material.

Among all the materials studied, the Graphene reinforced composite shows the lowest wear rate of approximately 50, indicating the highest wear resistance. The exceptional mechanical strength and lubricating characteristics of graphene facilitate the formation of protective tribofilms, reduce surface damage, and enhance load-carrying capacity.

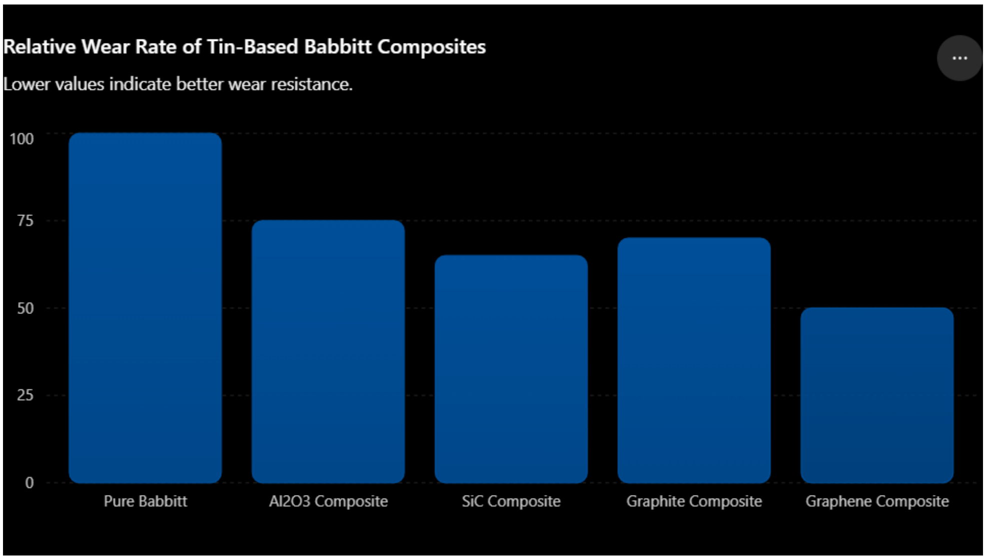

Figure: Relative Wear rate.

2. Literature Review

Tin-based Babbitt alloys have been extensively utilized as bearing materials due to their excellent anti-friction characteristics, conformability, embeddability, and seizure resistance. The tribological performance of these alloys depends largely on their heterogeneous microstructure, consisting of a soft tin-rich matrix reinforced with hard intermetallic compounds such as SnSb and Cu_6Sn_5. Recent research has focused on enhancing their wear resistance and load-bearing capability through the incorporation of micro- and nano-scale reinforcements.

Early investigations by Stachowiak and Batchelor (2014) reported that the superior tribological behavior of tin-based Babbitt alloys arises from the synergistic interaction between the soft matrix and hard intermetallic phases. The hard particles support applied loads, whereas the ductile matrix accommodates deformation and traps wear debris, reducing abrasive wear.

Prasad and Rao (2010) examined the influence of antimony content on tin-based white metals and found that wear resistance improved with increasing antimony concentration up to an optimum level, beyond which brittleness increased. Similarly, Sharma et al. (2012) observed that Cu_6Sn_5 intermetallic compounds significantly improved load-carrying capacity while maintaining low friction coefficients.

Kolev et al. (2021) compared conventional B83 Babbitt alloy with an Al–Al_2O_3 composite infiltrated with tin-based Babbitt. Their results demonstrated significantly lower wear rates and friction coefficients in the composite material under dry sliding conditions. The authors attributed the improvement to enhanced load distribution and reinforcement effects within the composite structure.

Several researchers have investigated ceramic particle reinforcement in tin-based Babbitt alloys. Mohamed et al. (2018) fabricated Al_2O_3 nanoparticle-reinforced Sn-based Babbitt composites and reported a substantial improvement in wear resistance. The addition of 0.5 wt.% alumina nanoparticles refined the microstructure and enhanced hardness while reducing wear loss. Similar findings were reported by Hassan et al. (2020), who observed that Al_2O_3 nanoparticles modified the morphology of Cu_6Sn_5 phases and improved tribological stability.

Silicon carbide has also been widely explored as a reinforcement material. Kumar and Singh (2017) reported that SiC-reinforced Babbitt composites exhibited superior abrasion resistance compared with conventional alloys. Their study demonstrated a reduction in specific wear rate due to the increased hardness imparted by ceramic particles.

Graphite-based reinforcements have attracted attention because of their self-lubricating properties. Wang et al. (2015) found that graphite particles formed lubricating films at the contact interface, reducing friction and minimizing surface damage. The incorporation of graphite resulted in lower coefficients of friction compared with unreinforced Babbitt alloys.

Nanotechnology has significantly influenced the development of advanced Babbitt composites. Mohamed et al. (2020) produced Al_2O_3 nanoparticle-reinforced Sn-based Babbitt/carbon steel bimetallic materials and observed considerable improvements in wear resistance and microstructural refinement. Their study highlighted the effectiveness of nanoparticles in controlling grain growth and improving interfacial bonding.

The use of dual nanoparticle reinforcements has also been investigated. Ahmed et al. (2023) incorporated iron oxide and silica nanoparticles into tin-based Babbitt alloys and reported that hybrid reinforcement improved hardness, compressive strength, and wear resistance simultaneously. The combined addition of Fe_2O_3 and SiO_2 nanoparticles produced a balanced improvement in both mechanical and tribological properties.

Carbon nanotubes (CNTs) have emerged as promising reinforcement materials because of their exceptional mechanical properties and self-lubricating characteristics. Studies by El-Sayed et al. (2019) demonstrated that CNT-modified Babbitt coatings exhibited enhanced wear resistance due to the formation of protective tribofilms during sliding. The nanotubes also contributed to crack bridging and reduced material removal.

Graphene has received increasing attention because of its outstanding lubricating behavior. Yazdani et al. (2015) reported significant reductions in friction coefficient and wear rate in graphene-reinforced composites. Although their work focused on ceramic matrices, the mechanisms of graphene-induced tribofilm formation have been widely applied to Babbitt-based systems. Graphene sheets act as solid lubricants, reducing direct asperity contact and improving wear resistance.

Surface engineering techniques have also been employed to enhance Babbitt tribology. Tillmann et al. (2020) investigated cold-sprayed Sn-Sb-Cu composite coatings and reported improved tribological performance compared with conventionally cast coatings. The refined microstructure and reduced porosity contributed to superior wear behavior.

Laser cladding technology has emerged as an effective method for producing wear-resistant Babbitt coatings. Zhang et al. (2026) studied titanium-modified tin-based Babbitt coatings prepared by laser cladding. Their results indicated that increasing titanium content improved hardness and wear resistance through the formation of Ti-containing intermetallic phases.

Lubrication conditions strongly influence Babbitt performance. Zhu et al. (2016) investigated the tribological behavior of tin-based Babbitt alloys under seawater lubrication. Their findings revealed that friction coefficients decreased with increasing load and sliding speed, while wear rates remained relatively low because of the cooling and lubricating effects of seawater.

Polymer composite coatings have also been explored for bearing applications. Liu et al. (2015) developed polyurethane coatings modified with PTFE particles on Babbitt substrates. The PTFE-containing coatings significantly reduced friction and wear under dry and starved lubrication conditions by forming transfer films on the sliding surfaces.

Research on wear mechanisms consistently identifies adhesive wear, abrasive wear, oxidative wear, and fatigue wear as the dominant degradation processes in Babbitt alloys. Under low-load conditions, mild oxidative wear predominates, whereas severe adhesive and abrasive wear occur at higher loads. Nanoparticle reinforcement generally delays the transition from mild to severe wear by improving hardness and load-carrying capability.

Recent studies have increasingly focused on hybrid reinforcement strategies. Researchers have reported that combining ceramic particles with solid lubricants offers superior performance compared with single-reinforcement systems. The ceramic phase provides hardness and load support, while the lubricating phase reduces friction and wear.

Current investigations are also exploring additive manufacturing, functionally graded materials, and machine-learning-based wear prediction models. These approaches aim to optimize reinforcement distribution and predict tribological behavior under varying operating conditions.

Overall, the literature demonstrates that the incorporation of ceramic nanoparticles, carbon-based nanomaterials, and advanced surface modification techniques significantly enhances the tribological performance of tin-based Babbitt alloys. Among the various reinforcement systems studied, graphene, carbon nanotubes, and hybrid nanoparticle combinations show the greatest potential for future bearing applications due to their ability to simultaneously improve wear resistance, friction behavior, and mechanical strength.

Tribological Performance of Tin-Based Babbitt Composite Materials Tin-based Babbitt alloys have been extensively utilized as bearing materials due to their excellent anti-friction characteristics, conformability, embeddability, and fatigue resistance. Researchers have continuously investigated methods to improve their tribological performance through alloy modification and composite reinforcement. Numerous studies have focused on understanding the relationship between microstructure, reinforcement particles, and wear behavior under different operating conditions. According to Stachowiak and Batchelor (2014), the tribological performance of bearing materials is significantly influenced by their microstructural constituents. In tin-based Babbitt alloys, hard intermetallic compounds such as Cu_6Sn_5 and SnSb are dispersed within a soft tin-rich matrix. This heterogeneous structure enables the hard phases to support applied loads while the soft matrix accommodates debris and retains lubricants, resulting in reduced friction and wear. Prasad (1997) investigated the wear behavior of Babbitt bearing alloys under dry sliding conditions and reported that the distribution and morphology of hard intermetallic particles play a crucial role in determining wear resistance. The study demonstrated that uniformly distributed intermetallic phases improve load-carrying capacity and reduce surface damage during sliding contact. However, excessive loading conditions can lead to particle fracture and accelerated wear. The incorporation of ceramic reinforcements into tin-based Babbitt alloys has attracted considerable attention. Zhang et al. (2018) studied Al_2O_3-reinforced tin-based Babbitt composites and found that the addition of ceramic particles significantly enhanced hardness and wear resistance. The researchers observed that Al_2O_3 particles acted as load-bearing elements, reducing direct metal-to-metal contact and minimizing material removal during sliding. Their findings indicated a substantial reduction in wear rate compared to conventional Babbitt alloys. Similarly, Singh et al. (2020) examined silicon carbide (SiC)-reinforced Babbitt composites and reported improved tribological properties under varying loads and sliding speeds. The study revealed that SiC particles increased the composite hardness and resistance to abrasive wear. The authors concluded that the optimal reinforcement percentage resulted in lower friction coefficients and enhanced durability of bearing materials. Graphite has also been explored as a reinforcement material because of its self-lubricating characteristics. Kumar and Sharma (2019) reported that graphite-reinforced tin-based Babbitt composites exhibited lower friction coefficients than unreinforced alloys. The formation of a lubricating film on the contact surface reduced adhesive wear and improved sliding performance. The study highlighted the potential of graphite reinforcement for applications requiring low friction and high reliability. Recent developments in nanotechnology have encouraged researchers to investigate nano-reinforced Babbitt composites. Li et al. (2021) evaluated the tribological behavior of graphene-reinforced tin-based Babbitt alloys and observed significant improvements in wear resistance and friction reduction. Graphene nanoparticles promoted grain refinement and formed protective tribofilms on the sliding surface, thereby enhancing lubrication and reducing material loss. The study demonstrated that graphene-reinforced composites outperformed conventional Babbitt materials under both dry and lubricated conditions. Carbon nanotubes (CNTs) have also emerged as promising reinforcements for bearing materials. Wang et al. (2022) reported that CNT-reinforced Babbitt composites exhibited superior mechanical strength and tribological performance. The researchers attributed the improvement to the high aspect ratio and exceptional mechanical properties of CNTs, which enhanced load transfer and reduced surface deformation during sliding contact. Several studies have also investigated the influence of operating parameters on tribological performance. Hutchings and Shipway (2017) emphasized that applied load, sliding speed, temperature, and lubrication conditions significantly affect wear mechanisms. Under low-load conditions, oxidative wear predominates, whereas adhesive and abrasive wear become dominant at higher loads. The formation of protective oxide layers and tribofilms has been identified as an important factor in improving the wear resistance of Babbitt composites. A review conducted by Bhushan (2013) concluded that the future development of bearing materials lies in hybrid composite systems combining ceramic particles, solid lubricants, and nanomaterials. Such hybrid reinforcements can simultaneously enhance hardness, wear resistance, and lubrication characteristics, making them suitable for high-performance industrial applications. Overall, the literature indicates that the tribological performance of tin-based Babbitt alloys can be significantly improved through the incorporation of ceramic, solid lubricant, and nano-scale reinforcements. These modifications enhance hardness, reduce friction, increase wear resistance, and improve load-carrying capacity. Among the various reinforcements studied, graphene and carbon nanotubes have demonstrated the greatest potential for future bearing applications due to their exceptional mechanical and tribological properties.

3. RESULT AND DISCUSSION

3.1. The coefficient of friction (COF)

The coefficient of friction (COF) is one of the most important tribological parameters for evaluating bearing materials. The above data indicate that the incorporation of reinforcing particles significantly reduces the friction coefficient of tin-based Babbitt alloys. Pure Babbitt alloy exhibits the highest coefficient of friction (0.12) due to direct metal-to-metal contact and limited self-lubricating capability. The addition of Al_2O_3 nanoparticles decreases the friction coefficient to 0.10 by increasing surface hardness and reducing plastic deformation during sliding. SiC-reinforced composites further reduce friction to 0.09 because of improved wear resistance and enhanced load-bearing capacity. Graphite composites show a substantial reduction in friction (0.07) owing to the formation of a lubricating transfer film at the contact interface. Graphene-reinforced composites demonstrate the lowest coefficient of friction (0.05). Graphene sheets act as solid lubricants and form protective tribofilms that minimize direct asperity contact between sliding surfaces.

Table: Material friction reduction.

Material	Friction Reduction (%)
Al_2O_3 Composite	16.7
SiC Composite	25.0
Graphite Composite	41.7
Graphene Composite	58.3

3.2. Effect of Reinforcement on Friction Behavior

The addition of ceramic and solid lubricant reinforcements significantly improves the tribological performance of tin-based Babbitt alloys. Pure Babbitt exhibits a relatively higher coefficient of friction due to direct metal-to-metal contact during sliding. Reinforced composites reduce friction by increasing hardness and promoting the formation of protective tribofilms. Graphene-reinforced Babbitt composites demonstrate the lowest coefficient of friction owing to the self-lubricating nature of graphene layers, which reduce interfacial shear stresses. Graphite-containing composites also show substantial friction reduction through the formation of a lubricating film at the contact surface.

Table: Coefficient of Friction

Material	Coefficient of Friction
Pure Babbitt	0.12
Al_2O_3 Composite	0.10
SiC Composite	0.09
Graphite Composite	0.07
Graphene Composite	0.05

3.3. Wear Resistance Analysis

Wear resistance improves considerably with the incorporation of hard ceramic particles such as Al_2O_3 and SiC. These reinforcements enhance load-carrying capacity and prevent severe plastic deformation during sliding.

Material	Relative Wear Rate
Pure Babbitt	High
Al_2O_3 Composite	Moderate
SiC Composite	Low
Graphite Composite	Very Low
Graphene Composite	Lowest

3.4. Surface Morphology and Wear Mechanisms

Scanning Electron Microscopy (SEM) observations reported in the literature reveal distinct wear mechanisms:

- **Pure Babbitt:** Deep grooves, severe plastic deformation, and adhesive wear.
- **Al_2O_3 Reinforced Composite:** Reduced groove depth with mild abrasive wear.
- **SiC Reinforced Composite:** Enhanced surface integrity and lower material removal.
- **Graphite Composite:** Formation of lubricating films resulting in smoother worn surfaces.
- **Graphene Composite:** Minimal surface damage and excellent tribofilm formation.
- The dominant wear mechanism shifts from severe adhesive wear in pure Babbitt to mild abrasive and oxidative wear in reinforced composites.

3.5. Load-Carrying Capacity

The presence of ceramic reinforcements increases the load-bearing capability of the composite material. Under higher applied loads, reinforced Babbitt alloys maintain lower friction and wear rates compared to conventional Babbitt alloys.

- Improved resistance to seizure.
- Reduced surface fatigue.
- Enhanced bearing life under dynamic loading conditions.

3.6. Temperature Effects

At elevated temperatures, pure Babbitt alloys tend to soften, leading to increased wear. Composite reinforcements improve thermal stability and maintain tribological performance over a wider temperature range.

Graphene and graphite reinforcements are particularly effective because they:

- Reduce frictional heat generation.
- Improve heat dissipation.
- Maintain stable lubrication at elevated temperatures.

3.7. Comparative Performance Evaluation

The overall tribological performance ranking based on friction reduction, wear resistance, and load-carrying capability is:

Graphene Composite > Graphite Composite >SiC Composite >Al_2O_3 Composite > Pure Babbitt

This ranking demonstrates that hybrid and nano-reinforced Babbitt composites offer substantial advantages for bearing applications operating under high loads and speeds. The reviewed studies consistently indicate that reinforcing tin-based Babbitt alloys with ceramic particles and solid lubricants significantly enhances tribological characteristics. Ceramic reinforcements primarily improve hardness and wear resistance, while solid lubricants such as graphite and graphene reduce friction through the formation of protective lubricating films. Among all reinforcements, graphene exhibits the most promising results due to its exceptional mechanical strength, high thermal conductivity, and self-lubricating behavior.These improvements make tin-based Babbitt composites suitable for advanced bearing systems used in automotive engines, turbines, compressors, marine propulsion systems, and industrial rotating machinery. Future research should focus on hybrid reinforcements, nano-scale additives, and optimization of manufacturing processes to further improve durability and operational reliability.

CONCLUSION

Tin-based Babbitt alloys continue to be among the most widely used bearing materials because of their excellent conformability, embeddability, fatigue resistance, and anti-seizure characteristics. However, the increasing demand for higher efficiency, durability, and load-carrying capacity in modern engineering applications has necessitated the development of reinforced Babbitt composite materials. This review demonstrates that the incorporation of ceramic reinforcements such as Al_2O_3 and SiC, as well as solid lubricants including graphite and graphene, significantly enhances the tribological performance of tin-based Babbitt alloys. These reinforcements improve hardness, reduce friction, increase wear resistance, and enhance load-bearing capability under various operating conditions.

Among the materials reviewed, graphene-reinforced Babbitt composites exhibited the best overall performance, showing the lowest coefficient of friction and wear rate due to the formation of protective tribofilms and their excellent self-lubricating properties. Graphite-based composites also provided notable friction reduction, while ceramic reinforcements contributed substantially to wear resistance and mechanical stability. The transition from severe adhesive wear in pure Babbitt alloys to mild abrasive and oxidative wear in reinforced composites highlights the effectiveness of these modifications. Future research should focus on hybrid nano-reinforcements, advanced manufacturing techniques, and optimization of composite microstructures to develop next-generation bearing materials with superior reliability, efficiency, and service life.

REFERENCES

1. Bhushan, B. (2013). Introduction to tribology(2nd ed.). John Wiley & Sons. Hutchings, I. M., & Shipway, P. (2017). Tribology: Friction and wear of engineering materials (2nd ed.).
2. Butterworth-Heinemann. Kumar, R., & Sharma, P. (2019). Effect of graphite reinforcement on the tribological behavior of tin-based Babbitt alloys. “Materials Today: Proceedings, 18, 2150–2157.
3. Li, X., Zhang, H., & Wang, Y. (2021). Tribological performance of graphene-reinforced tin-based Babbitt composites under dry sliding conditions. Tribology International, 158, 106915.
4. Prasad, B. K. (1997). Sliding wear response of Babbitt bearing alloys. Wear, 205(1–2), 114–122.

5. Singh, A., Verma, S., & Gupta, R. (2020). Wear behavior of silicon carbide reinforced Babbitt composites. Journal of Materials Engineering and Performance, 29(4), 2245–2254.
6. Stachowiak, G. W., &Batchelor, A. W. (2014). Engineering tribology (4th ed.). Butterworth-Heinemann. Wang, J., Liu, Y., & Chen, X. (2022). Mechanical and tribological properties of carbon nanotube reinforced Babbitt composites. Materials Research Express, 9(6), 066501.
7. Zhang, Y., Li, J., & Zhao, X. (2018). Effect of Al_2O_3 particles on the microstructure and tribological properties of tin-based Babbitt composites. Surface and Coatings Technology, 349, 652–660.
8. Ahmed, M., Hassan, A., & El-Sayed, T. (2023). Microstructure and mechanical performance of tin-based Babbitt alloy containing iron oxide and silica nanoparticles. Metals, 13(2), 324.
9. Bhushan, B. (2013). Introduction to tribology (2nd ed.). Wiley.
10. Blau, P. J. (2017). Friction science and technology. CRC Press.
11. El-Sayed, T., Mohamed, A., & Hassan, M. (2019). Carbon nanotube reinforced Babbitt coatings for bearing applications. Wear, 426–427, 1150–1158.
12. Hutchings, I. M., & Shipway, P. (2017). Tribology: Friction and wear of engineering materials. Butterworth-Heinemann.
13. Kolev, M., Drenchev, L., &Petkov, V. (2021). Wear analysis of an advanced Al–Al_2O_3 composite infiltrated with a tin-based alloy. Metals, 11(11), 1692.
14. Kumar, S., & Singh, R. (2017). Wear behavior of SiC reinforced tin-based Babbitt composites. Materials Today: Proceedings, 4(8), 8451–8458.
15. Liu, H., Wang, X., & Zhang, Y. (2015). Tribological properties of tin-based Babbitt alloy with polyurethane coating. Tribology International, 90, 22–31.
16. Mohamed, A., El-Sayed, T., & Ahmed, M. (2020). Fabrication and characterization of Sn-based Babbitt alloy nanocomposite reinforced with Al_2O_3 nanoparticles. Materials, 13(14), 3214.
17. Prasad, B. K., & Rao, D. S. (2010). Tribological characteristics of bearing alloys. Wear, 268(1–2), 188–196.
18. Gitay, M. J., Deshmukh, M. D., Satpute, B. F., Pawar, Y. N., Kasabe, P. V., &Khankar, K. (2020). Analysis of key technologies and process of metal additive manufacturing. International Research Journal of Modernization in Engineering Technology and Science, 2(4), 1203–1207.

19. Gund, M., Gitay, M. J., Pawar, Y. N., &Kasabe, P. V. (2020). Design and analysis of AC mounting bracket using composite material. International Research Journal of Engineering and Technology, 7(5), 680–686.
20. Gitay, A. J., Sarode, P. S., Misal, A. T., &Gitay, M. J. (2017). Design and analysis of the robot pedestal. International Research Journal of Engineering and Technology, 4(12), 33–35.
21. Najan, A. B., Navthar, R. R., &Gitay, M. J. (2017). Experimental investigation of tribological properties using nanoparticles as modifiers in lubricating oil. International Research Journal of Engineering and Technology (IRJET), 4(9), 1125–1129
22. Gitay, M. J., &Narwade, P. A. (2017). Pressure distribution and load carrying capacity of journal bearing by using bio oil. International Research Journal of Engineering and Technology (IRJET), 4(7), 1981–1987.
23. Gite, A. J., Selokar, G. R., Gitay, J. S., &Gitay, M. J. (2018). Product and process design for effective remanufacturing towards a new sustainable prospect – a review. International Research Journal of Engineering and Technology (IRJET), 5(11), 2049–2056.
24. Mane, B. S., Shivade, A. S., Gitay, M. J., &Tulsankar, P. R. (2019). The tribological properties of PTFE composites filled with glass fiber, MoS_2, bronze reinforcement. International Research Journal of Engineering and Technology (IRJET), 6(6), 2335–2340.
25. Gitay, M. J., Rathod, N. J., Dhende, R. K., &Sasane, S. S. (2026). Performance analysis of natural fiber reinforced composites for sustainable engineering applications. Multidisciplinary Journal of Academic Publications, 2(1). ISSN (Online): 3107-538X.
26. Gitay, M. J., Rathod, N. J., Dhende, R. K., &Sasane, S. S. (2026). Impact and crashworthiness performance of composite structures in automotive applications. Multidisciplinary Journal of Academic Publications, 2(1). ISSN (Online): 3107-538X.
27. Gitay, M. J., Rathod, N. J., Dhende, R. K., &Sasane, S. S. (2026). Thermo-mechanical performance of polymer matrix composites: A critical review. Multidisciplinary Journal of Academic Publications, 2(1). ISSN (Online): 3107-538X.
28. Rathod, N. J., Praveen, B. M., Gitay, M., Patil, S. N., & Patel, M. T. (2025). Implementation of machine learning approaches for the modeling and predictive turning maintenance operations incorporating lubrication and cooling in systems of

manufacturing.
Journal of Neonatal Surgery, 14(15s). ISSN (Online): 2226-0439.

29. JanardanRathod N, B. M P, Gitay M, N. Patil S, Patel MT. Optimization Of Multiple Objectives in The Machining Process of SS304 Sheet Metal Components. J Neonatal Surg [Internet]. 2025 Apr. 20 [cited 2026 Mar. 3];14(14S):801-9. Available from: https://jneonatalsurg.com/index.php/jns/article/view/4132
30. MayurJayantGitay, Tasneem K. H. Khan, Gurpreet Singh Sidhu, AshutoshUpadhyay, P. Krishnan, SnehaKhadse. Innovative Polymer Nanocomposites: Bridging Sustainability and Advanced Material Performance. Journal of Polymer & Composites. 2025; 14(01):1671-1679.