Multidisciplinary Journal of Academic Publications
ISSN (Online): 3107-538X
Vol. 02, Issue 01, January – February 2026

PERFORMANCE ANALYSIS OF NATURAL FIBER REINFORCED COMPOSITES FOR SUSTAINABLE ENGINEERING APPLICATIONS

Dr. Mayur Jayant Gitay[1], Dr. Nikhil J. Rathod[2], Mr. Rohit K. Dhende[3], Mr. Sagar S. Sasane[4]

Assistant Professor, Department of Mechanical Engineering, ATC, Ahilyanagar[1]

Assistant Professor, Department of Mechanical Engineering, BVCOE & RI, Nashik[2]

Lecturer, Department of Mechanical Engineering, HSBPVT's Parikrama Polytechnic, Kashti[3]

PhD Scholar, Department of Mechanical Engineering, Sandip University, Nashik[4]

Abstract

Research on natural fibre reinforced composites (NFRCs) as potential substitutes for traditional synthetic fibre composites has intensified due to the growing need for ecologically friendly and sustainable engineering materials. Natural fibres with low density, biodegradability, renewability, affordability, and a lower carbon footprint include jute, sisal, kenaf, flax, hemp, bamboo, and coir. With an emphasis on their mechanical, thermal, tribological, and environmental properties for sustainable engineering applications, this study offers a thorough performance analysis of natural fibre reinforced composites. Usually, natural fibres in different weight fractions and orientations are mixed with polymer matrices like epoxy, polyester, polypropylene, or biodegradable resins to create composites. Tensile, flexural, impact, and compressive qualities are the main focus of the performance evaluation, which also highlights how fibre type, length, volume fraction, surface treatment, and fabrication method affect the behaviour of the composite as a whole. The function of chemical treatments like acetylation, silane, and alkali in enhancing moisture resistance and fiber–matrix interfacial bonding, which in turn improves mechanical performance and durability, is explored.

Keywords: *mechanical qualities[1], hybrid composites[2], natural fibres[3], engineering applications[4], sustainability[5], reinforced composites[6].*

1. Introduction

The engineering sectors have seen substantial changes in material selection and design techniques due to the growing emphasis on sustainable development and environmental protection. Because of their superior durability and high strength-to-weight ratio, conventional composite materials reinforced with synthetic fibres like glass, carbon, and aramid have been employed extensively. However, these materials have significant disadvantages, such as high production energy consumption, non-biodegradability, difficulties with recycling, and negative environmental effects. Natural fibre reinforced composites (NFRCs) have become viable sustainable substitutes for a variety of engineering uses in response to these constraints. Low density, biodegradability, affordability, and accessibility are just a few of the inherent benefits of natural fibres made from renewable plant sources like jute, flax, hemp, sisal, kenaf, bamboo, banana, and coir. These fibres interact with thermosetting and thermoplastic polymer matrices to create composites that have acceptable mechanical qualities while drastically lowering their environmental impact. Because lightweight and environmentally friendly materials are crucial in industries such consumer products, construction, automotive, packaging, and marine, NFRCs have drawn more attention.

2. Overview of NFRCS

Natural fibres are utilised as reinforcement in a polymeric, metallic, or biodegradable matrix to create Natural Fibre Reinforced Composites (NFRCs). The potential of these composites to replace traditional synthetic fibre composites in situations where cost-effectiveness, low weight, and sustainability are important factors has drawn a lot of interest in recent years. The matrix holds the reinforcement fibres together, transfers load, and shields them from mechanical and environmental degradation. The reinforcement fibres are usually obtained from renewable plant sources. Jute, flax, hemp, kenaf, sisal, coir, banana, bamboo, and ramie are among the natural fibres frequently utilised in NFRCs. These fibres are widely available, biodegradable, low in density, and have a respectable specific strength. Natural fibres can be divided into three categories based on where they come from: plant, animal, and mineral. Plant fibres are the most widely employed in engineering applications. Cellulose, hemicellulose, lignin, and pectin make up the majority of plant fibres, and their composition has a major impact on mechanical behaviour, moisture absorption, and thermal stability. The total performance of NFRCs is significantly influenced by the matrix material. Both thermoplastic polymers like polypropylene, polythene, and polylactic acid (PLA) and thermosetting polymers like epoxy, polyester, and vinyl ester are frequently used. To increase the environmental advantages of NFRCs, biodegradable and bio-based matrices have become more popular in recent years. Because inadequate interfacial bonding can result in decreased load transfer efficiency and subpar mechanical qualities, compatibility between the fibre and matrix is crucial.

3. Literature Survey

1. Biodegradable NFRCs' Durability and Mechanical Performance (2024)

The mechanical performance, durability characteristics, manufacturing processes, and degrading behaviour of biodegradable natural fiber-reinforced composites are all thoroughly examined in a recent review. Fiber-matrix interactions, typical failure modes, and how surface treatments and nanostructure integration enhance performance while preserving biodegradability are all covered. In order to completely optimise NFRCs for engineering applications, more research is required. The evaluation also evaluates end-of-life scenarios including recycling and degradation.

2. Current Advances in Thermal, Mechanical, and Machinability Properties (2024)

With an emphasis on mechanical, thermal, and machinability features, this paper offers a comprehensive summary of current developments in NFCs. It contrasts several natural fibres and explains how fibre features, treatments, and composite processing impact attributes including tensile strength, thermal stability, and processability. Applications in industries like power systems, automotive, and aerospace are highlighted.

3. NFRCs' Chemical, Physical, and Thermo-Mechanical Properties (2023)

A thorough analysis looks at the mechanical strength, thermal properties, physical behaviour, and chemical makeup of natural fibre composites. It draws attention to these materials' sustainability and adaptability as well as their drawbacks, like moisture sensitivity and durability issues. Important property trends that are pertinent to design and application issues are also included in the study.

4. Developments in Hybrid Composites with Renewable Natural Fibre (2024)

In order to enhance composite behaviour, this review focuses on hybrid composites that combine natural fibres with additional reinforcements. It assesses dimensional stability, hydrophilicity reduction, interfacial bonding mechanisms, and mechanical enhancements brought about by hybridization techniques..

5. Natural fiber-reinforced polymers' sustainability (2024)

Environmental and lifespan characteristics of NFRCs are examined in a 2024 sustainability evaluation. In comparison to synthetic composites, it evaluates sustainability indicators such recyclability, carbon footprint reduction, renewability, and overall ecological impact. It also emphasises how environmental benefits in engineering applications are influenced by material selection, processing routes, and design optimisation.

4. Challenges in NFRC Systems

Natural Fibre Reinforced Composites (NFRCs) have a lot of potential for sustainable engineering applications, but their widespread use is hampered by a number of industrial, technological, and environmental issues. Improving composite performance, guaranteeing dependability, and facilitating widespread industrial use all depend on an understanding of these difficulties.

1. Variability and Inconsistency of Fibre

The inherent variety of natural fibre characteristics is one of the main issues with NFRC systems. The mechanical, physical, and chemical properties of natural fibres, which are agricultural products, differ greatly based on plant species, growing circumstances, harvesting time, extraction techniques, and geographic location. In contrast to synthetic fibre composites, this heterogeneity results in unpredictable composite characteristics, making standardisation and quality control challenging.

2. Inadequate Interfacial Bonding between Fibre and Matrix

Because cellulose contains hydroxyl groups, natural fibres are hydrophilic, whereas the majority of polymer matrices are hydrophobic. Weak interfacial bonding, ineffective load transfer, and early failure under mechanical loading are the outcomes of this mismatch. Additionally, poor adhesion makes fibre pull-out and delamination more likely, which lowers NFRCs' tensile, flexural, and impact strengths.

3. Absorption of Moisture and Sensitivity to the Environment

One of NFRCs' main drawbacks is their high moisture absorption. Water from the environment is easily absorbed by natural fibres, which over time causes swelling, dimensional instability, matrix cracking, and mechanical property loss. Composites cannot be used in outdoor and high-humidity applications without protective coatings or treatments because exposure to humidity, rain, or marine environments can drastically diminish their durability.

4. Inadequate Heat Stability

The usual thermal breakdown temperature range for natural fibres is between 200 and 250 °C. This restricts their suitability for thermoplastic matrices that need high moulding temperatures and high-temperature processing methods. Because of this, NFRCs have processing issues during injection moulding or extrusion and are not appropriate for high-temperature structural applications.

5. Weaker Mechanical Strength in Relation to Artificial Composites

The absolute mechanical properties of NFRCs are typically inferior to those of glass or carbon fibre reinforced composites, despite the fact that they provide good specific strength and stiffness. This primarily limits their use to non-structural or semi-structural elements. Increased fibre content or hybridization are frequently needed to provide greater strength, which could jeopardise processability or sustainability advantages.

6. Problems with Durability and Long-Term Performance

NFRCs are vulnerable to cyclic loading, thermal ageing, UV exposure, and biological deterioration. These elements may eventually lead to matrix embrittlement, interfacial strength loss, and fibre deterioration. Due to a lack of long-term field data and standardised testing procedures, long-term performance prediction and durability assessment continue to be difficult.

5. Comparative Analysis

To determine whether Natural Fibre Reinforced Composites (NFRCs) are suitable for sustainable engineering applications, a comparison with other engineering materials and traditional synthetic fibre reinforced composites is necessary. The mechanical performance, physical characteristics, thermal behaviour, environmental impact, cost, processing, and prospective applications of NFRCs are all compared in this section.

1. Comparison of Mechanical Properties

When compared to glass fibre reinforced composites (GFRPs) and carbon fibre reinforced composites (CFRPs), natural fibre composites often show lower absolute tensile, flexural, and impact strength. Nonetheless, NFRCs have competitive specific strength and stiffness because of their low density, which makes them appropriate for lightweight applications. Because of their higher cellulose content and superior fibre alignment, flax and hemp composites frequently exhibit greater tensile and flexural strength than jute and coir composites. While NFRCs are better suited for non-structural and semi-structural components, synthetic fibre composites continue to rule high-load structural applications.

2. Weight and Density Considerations

Compared to glass fibre composites, which have a density of about 2.5 g/cm³, NFRCs typically have a density of 1.2–1.5 g/cm³. In transportation applications where fuel efficiency and emission reduction are crucial, including automobile interiors and panels, this weight reduction is beneficial. Even lower density is possible with carbon fibre composites, but the cost of materials and production is significantly higher.

3. Comparison of Thermal Performance

Synthetic fibre composites perform better than NFRCs in terms of heat stability. While natural fibres deteriorate at comparatively lower temperatures, glass and carbon fibres can tolerate higher processing and service temperatures. Applications below moderate temperature ranges are often the only ones that can use NFRCs. Nonetheless, NFRCs' thermal performance is sufficient and on par with polymer-based composites for interior and ambient-condition applications.

4. Absorption of Moisture and Resistance to the Environment

Because natural fibres are hydrophilic, natural fibre composites absorb more moisture, which reduces their mechanical performance and dimensional stability under humid conditions. Synthetic fibre composites, on the other hand, have better chemical and moisture resistance. Although they increase processing complexity, surface treatments and protective coatings might lessen this disadvantage in NFRCs.

5. Wear and Tribological Behaviour

NFRCs exhibit respectable wear resistance under low to moderate stress levels, according to comparative studies. Natural fibres like sisal and jute can improve frictional stability and lessen abrasive wear in some applications, whereas glass fibre composites offer superior wear resistance in harsh environments. NFRCs are hence appropriate for non-critical tribological components.

6. Discussion

Natural Fibre Reinforced Composites (NFRCs) have increasing promise as sustainable substitutes for traditional synthetic fibre composites, as demonstrated by their performance study and comparative evaluation. This section's discussion critically examines the consequences for real-world engineering applications while integrating the results of mechanical, thermal, tribological, and sustainability assessments. The mechanical performance of NFRCs shows that when suitable fibre selection, surface treatment, and processing methods are used, these materials can reach acceptable tensile, flexural, and impact capabilities. Because they have a higher cellulose content and better microstructural alignment than jute and coir, fibres like flax, hemp, and kenaf regularly perform better mechanically. To guarantee consistent composite performance, however, variability in natural fibre characteristics continues to be a major challenge, highlighting the need for better fibre grading, standardisation, and quality control. The overall behaviour of the composite is largely determined by the interfacial bonding between the fibre and matrix. Chemical treatments like alkali and silane treatments greatly improve fiber–matrix adhesion, resulting in better load transmission and decreased fibre pull-out, according to the discussion of current studies. These treatments increase moisture resistance and mechanical qualities, but they also add extra processing steps and expenses that must be carefully weighed against sustainability goals.

According to thermal and environmental performance data, NFRCs are appropriate for applications that operate in controlled environments and at moderate temperatures. Natural fibres' comparatively low thermal degradation temperature restricts their use in high-temperature applications, but this restriction is acceptable for consumer goods, building materials, and car interior components. Since moisture absorption compromises long-term durability and dimensional stability, it remains a significant problem. Although there are currently few long-term field performance data, the application of surface coatings, hybrid composites, and moisture-resistant matrices has showed promise in reducing these impacts. According to tribological behaviour studies, under low to moderate loading circumstances, NFRCs can offer steady friction and respectable wear resistance. Natural fibre composites provide benefits including less abrasiveness, less noise, and eco-friendly wear detritus, but they do not perform better than synthetic fibre composites in harsh tribological settings. They are therefore appropriate for some non-critical tribological components.

7. Conclusion

The viability of Natural Fibre Reinforced Composites (NFRCs) for sustainable engineering applications is highlighted in this study's thorough performance investigation. The study demonstrates that NFRCs provide a practical and eco-friendly substitute for traditional synthetic fibre composites, especially in situations where sustainability, lightweight features, and moderate mechanical performance are important. The investigation shows that fibre type, fibre content, orientation, surface treatment, and processing methods all have a significant impact on the mechanical properties of NFRCs. When successful fiber–matrix interfacial bonding is accomplished, natural fibres including flax, hemp, kenaf, and jute exhibit favourable tensile and flexural behaviour. Although they add more processing considerations, chemical surface treatments greatly improve adhesion, lessen moisture sensitivity, and improve overall composite performance. NFRCs are appropriate for applications working in ambient and moderately high temperature conditions, according to thermal and environmental assessments. Even though their thermal stability is less than that of synthetic fibre composites, it is nevertheless sufficient for consumer goods, building materials, furniture, and automobile interior components. Long-term durability and moisture absorption are still major obstacles, although recent developments in protective coatings, hybridization, and fibre treatments have shown encouraging gains.

8. References

1. M. Ramesh, C. Deepa, and M. R. Sanjay, “Mechanical performance and durability attributes of biodegradable natural fibre-reinforced composites: A comprehensive review,” *J. Mater. Sci.: Mater. Eng.*, Springer, vol. 12, pp. 1–22, 2024, doi: 10.1186/s40712-024-00198-0.
2. K. Senthilkumar, R. Prakash, and V. Arumugam, “Recent developments in mechanical, thermal and machinability properties of natural fibre composites,” *Adv. Mater. Res.*, Scientific.Net, vol. 1148, pp. 61–78, 2024, doi: 10.4028/www.scientific.net/AMR.1148.61.
3. M. R. Sanjay, G. R. Arpitha, and B. Yogesha, “Chemical, physical and thermo-mechanical properties of natural fibre reinforced polymer composites: A review,” *J. Fibre-Reinf. Plast. Compos.*, Ge Society Journals, vol. 5, no. 2, pp. 45–63, 2023.
4. G. Koronis, A. Silva, and M. Fontul, “Advances in renewable natural fibre hybrid composites: Materials, properties and applications,” *J. Cleaner Prod.*, Elsevier, vol. 430, p. 139676, 2024, doi: 10.1016/j.jclepro.2024.139676.
5. M. Jawaid, M. T. Thariq, and N. Saba, “Sustainability of natural-fiber-reinforced polymer composites: Environmental and life-cycle perspectives,” *Sustainability*, MDPI, vol. 16, no. 3, p. 1223, 2024, doi: 10.3390/su16031223.
6. S. Kamarudin, et al., "Performance and sustainability of natural fiber reinforced composites," Polymers, vol. 14, no. 17, p. 3698, 2022.
7. C. W. Isaac and C. Ezekwem, "Crashworthiness performance of energy absorbing composite structures: materials, manufacturing and sustainability," Composite Structures, vol. 257, p. 113081, 2021.
8. X. Y. Ang, K. L. Tan, and H. Y. Lee, "Impact and crashworthiness performance of bio-composite crash boxes for automotive applications," Materials Today: Proceedings, vol. 75, pp. 1985–2001, 2023.
9. Q. Li, Y. Zhang, and J. Wu, "Crashworthiness enhancement techniques for hybrid composite structures," Composite Structures, vol. 306, p. 116091, 2024. [5] X. Zhao and P. Lu, "Influence of ply

orientation and composite architecture on crashworthiness under dynamic loading," Int. J. Impact Eng., vol. 163, p. 104145, 2022.
10. G. L. Farley and R. M. Jones, "Crushing characteristics of continuous fiber-reinforced composite tubes," J. Compos. Mater., vol. 26, pp. 37–50, 1992.
11. S. Ramakrishna and H. Hamada, "Energy absorption characteristics of crash-worthy structural composite materials," Key Eng. Mater., vol. 141–143, pp. 585–620, 1998.
12. G. C. Jacob, J. F. Fellers, S. Simunovic, and J. M. Starbuck, "Energy absorption in polymer composites for automotive crashworthiness," J. Compos. Mater., 2002.
13. P. R. Barnett, L. Vigna, J. L. Martínez-Collado, and D. Penumadu, "Crashworthiness of recycled carbon fiber composite sinusoidal structures at dynamic rates," Composite Structures, vol. 311, p. 116847, 2023.
14. Author E., "Hybridization effect on crashworthiness parameters of natural composites," Frontiers in Materials, vol. 8, p. 619245, 2021.
15. S. K. Pradhan, et al., "Review of natural fiber reinforced composites for automotive applications," Compos. Part B, 2022.
16. R. Gupta and A. Sharma, "Hybrid natural fiber-synthetic composites for sustainable applications," Compos. Struct., 2021.
17. M. Ali and F. Khan, "Mechanical performance of flax and hemp composites," Polymers, 2023.
18. J. Wang, et al., "Surface treatment effects on natural fiber composites," J. Appl. Polym. Sci., 2022.
19. L. Chen and S. Zhao, "Life cycle assessment of natural fiber reinforced composites," Int. J. Life Cycle Assess., 2023.
20. T. Singh and P. Verma, "Environmental benefits of natural fiber composites," J. Cleaner Prod., 2022.
21. Rathod, N.J., Chopra, M.K., Chaurasiya, P.K. et al. Optimization on the Turning Process Parameters of SS 304 Using Taguchi and TOPSIS. Ann. Data. Sci. 10, 1405–1419 (2023). https://doi.org/10.1007/s40745-021-00369-2
22. Rathod, N.J., Chopra, M.K., Shelke, S.N. et al. Investigations on hard turning using SS304 sheet metal component grey based Taguchi and regression methodology. Int J Interact Des Manuf 18, 2653–2664 (2024). https://doi.org/10.1007/s12008-023-01244-5
23. N.J. Rathod, M.K. Chopra, U.S. Vidhate, N.B. Gurule, U.V. Saindane, Investigation on the turning process parameters for tool life and production time using Taguchi analysis, Materials Today: Proceedings, Volume 47, Part 17, 2021, Pages 5830-5835, https://doi.org/10.1016/j.matpr.2021.04.199.
24. Rathod, N.J., Chopra, M.K., Chaurasiya, P.K. et al. Design and optimization of process parameters for hard turning of AISI 304 stainless steel using Taguchi-GRA-PCA. Int J Interact Des Manuf 17, 2403–2414 (2023). https://doi.org/10.1007/s12008-022-01021-w
25. Rathod, N.J., Chopra, M.K., Chaurasiya, P.K. et al. Optimization of Tool Life, Surface Roughness and Production Time in CNC Turning Process Using Taguchi Method and ANOVA. Ann. Data. Sci. 10, 1179–1197 (2023). https://doi.org/10.1007/s40745-022-00423-7
26. N.J. Rathod, M.K. Chopra, U.S. Vidhate, U.V. Saindane, Multi objective optimization in turning operation of SS304 sheet metal component, Materials Today: Proceedings, Volume 47, Part 17, 2021, Pages 5806-5811, https://doi.org/10.1016/j.matpr.2021.04.143
27. P. K. Chaurasiya, N. J. Rathod, P. K. Jain, V. Pandey, Shashikant and K. Lala, "Material Selection for Optimal Design Using Multi-Criteria Decision Making," 2023 3rd International Conference on Advancement in Electronics & Communication Engineering (AECE), GHAZIABAD, India, 2023, pp. 206-210, doi: 10.1109/AECE59614.2023.10428303.
28. Mahesh T. Dhande, et al. 2023. HMCMA: Design of an Efficient Model with Hybrid Machine Learning in Cyber security for Enhanced Detection of Malicious Activities. International Journal on Recent and Innovation Trends in Computing and Communication. 11, 11s (Oct. 2023), 721–734. DOI:https://doi.org/10.17762/ijritcc.v11i11s.9729.

29. T. Dhande M, Tiwari S, Rathod N. Design of an efficient Malware Prediction Model using Auto Encoded & Attention-based Recurrent Graph Relationship Analysis. Int. Res. J. multidiscip. Technovation [Internet]. 2025 Jan. 22 [cited 2025 Dec. 13];7(1):71-87. Available from: https://asianrepo.org/index.php/irjmt/article/view/103
30. Kalangi, C., Rathod, N.J., Madhuri, K.S. et al. Performance optimization of ethanol blends in diesel model using Taguchi and grey relational approach. Sci Rep 15, 36048 (2025).
31. Rathod, N.J., Bonde, P. & Nehete, H.R. Parametric optimization of WEDM of SS 304 stainless steel for material removal rate and surface roughness using Taguchi and Response Surface Methodology. Interactions 246, 60 (2025). https://doi.org/10.1007/s10751-025-02273-0
32. Nikhil Janardan Rathod , Praveen B. M. , Mayur Gitay, Sidhhant N. Patil, Mohan T. Patel, (2025) Optimization Of Multiple Objectives in The Machining Process of SS304 Sheet Metal Components.. Journal of Neonatal Surgery, 14 (14s), 801-809
33. Rathod, N.J. et al. (2026). Wire Electrical Discharge Machining Process Parameter Optimization via the Taguchi Method. In: Al-Ramahi, N., Musleh Al-Sartawi, A.M.A., Kanan, M. (eds) Artificial Intelligence in the Digital Era. Studies in Systems, Decision and Control, vol 594. Springer, Cham.
34. Rathod, N.J. *et al.* (2026). Aluminum Machining Process Parameter Optimization in WEDM with the GRA Approach. In: Al-Ramahi, N., Musleh Al-Sartawi, A.M.A., Kanan, M. (eds) Artificial Intelligence in the Digital Era. Studies in Systems, Decision and Control, vol 594. Springer, Cham.
35. Rathod, N.J. et al. (2026). Optimizing Wire Electric Discharge Machining Process Parameters for AISI 304 Stainless Steel via Taguchi Design of Experiments. In: Al-Ramahi, N., Musleh Al-Sartawi, A.M.A., Kanan, M. (eds) Artificial Intelligence in the Digital Era. Studies in Systems, Decision and Control, vol 594. Springer, Cham. https://doi.org/10.1007/978-3-031-89771-9_8
36. Rathod, N.J. et al. (2026). SS304 CNC Turning Process Mathematical Modeling and Machining Parameter Optimization Utilizing the Taguchi Technique. In: Al-Ramahi, N., Musleh Al-Sartawi, A.M.A., Kanan, M. (eds) Artificial Intelligence in the Digital Era. Studies in Systems, Decision and Control, vol 594. Springer, Cham. https://doi.org/10.1007/978-3-031-89771-9_2
37. Nikhil Janardan Rathod, Praveen B. M., Mayur Gitay, Sidhhant N. Patil, Mohan T. Patel, (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), 1741-1748
38. Nikhil J. Rathod, Nilesh Ingale, Mahesh T. Dhande, Santhosh H Pawar, A REVIEW ON AI ENABLED MULTI MODEL CARDIOVASCULAR MONITORING SYSTEM FOR PREDICTION OF PHYSIOLOGICAL STRESS, Department of Computer Science and Technology, 2025, 180724/IJORAR-1019,
39. Mayur Jayant Gitay, Dr. Nilesh Diwakar, Dr. M. K. Chopra, Dr. Nikhil J. Rathod, Analysis of the performance of a CI engine operating in dual fuel mode with biogas and biodiesel, Eur. Chem. Bull. 2023,12(3) 4462-4472
40. Prashant S. Raut, Dr. Nilesh Diwakar, Sumit Raut, Dr. Nikhil J. Rathod, Performance Evaluation and Emission Characteristic of Biodiesel (Methyl Ester) CI Engine, Eur. Chem. Bull. 2023, 12 (S3), 2240 – 2245
41. Sumit R. Raut, Dr. Nilesh Diwaka, Prashant S. Raut, Dr. N. J. Rathod, Additives Characterization for Enhanced Biodiesel Performance in a CI Engine, Eur. Chem. Bull. 2023, 12 (S3), 2234 – 2239
42. Sumit R. Raut, Dr. Nilesh Diwakar, Prashant S. Raut, Dr. N. J. Rathod, The Technique Performance Evaluation and Emission Characteristics of diesel, cerium oxide, and ethanol, Eur. Chem. Bull. 2023, 12 (S3), 3172 – 3184.
43. Prashant S. Raut, Dr. Nilesh Diwakar, Sumit Raut, Dr. Nikhil J. Rathod, The Technique Performance Evaluation and Emission Characteristics of Biodiesel, Eur. Chem. Bull. 2023, 12 (S3), 3147 – 3155