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We are delighted to present Volume 2, Issue 4 of the *Journal of Computers, Mechanical and Management (JCMM)*, which brings together a selection of six articles that embody the journal's interdisciplinary focus. This issue encompasses topics ranging from advancements in accessibility technologies and quantum computing to sustainability in traditional industries and material science innovations.

The issue begins with a study on enhancing email accessibility for visually impaired individuals. This research [1] introduces a voice-based email system powered by artificial intelligence, offering a novel solution for improving digital inclusivity. The system's use of AI and speech recognition not only aids those with visual impairments but also underscores the potential for AI-driven accessibility solutions across digital communication platforms.

Next, an article explores the financial soundness of Nepal's commercial banking sector through the CAMEL analysis framework [2]. The study offers critical insights into the sector's capital adequacy, asset quality, and management efficiency, shedding light on the factors that influence the stability and growth of financial institutions in emerging economies.

We also feature an article that delves into quantum computing, presenting the design and implementation of a multi-operative reversible gate for quantum-based parity generators [3]. This research highlights advancements in Quantum-dot Cellular Automata (QCA) as a promising alternative to CMOS technology, pushing the boundaries of high-speed, low-power computing and its applications in secure data handling.

Sustainability is addressed in a mini-review focused on the impact of the Goods and Services Tax (GST) on India's handicraft sector [4]. This article examines how GST has influenced traditional industries, emphasizing the need for sustainable practices and offering recommendations for balancing cultural preservation with economic growth.

Another noteworthy study explores the role of aluminum matrix composites reinforced with MgO particulates, highlighting their mechanical and wear-resistant properties [5]. The findings have significant implications for industries that rely on lightweight, durable materials, such as aerospace and automotive engineering.

Finally, we present an exploration of marine entrepreneurship, which investigates opportunities in aquaculture, eco-tourism, and marine biotechnology [6]. This study emphasizes the potential for sustainable innovation within the marine sector, proposing that entrepreneurs can both protect marine ecosystems and drive economic growth by adopting responsible practices.

As JCMM continues to grow, we remain committed to publishing diverse research that bridges disciplines and stimulates further investigation. We extend our deepest gratitude to our authors, reviewers, and the editorial team for their dedication and contributions. We hope this issue inspires our readers and supports their efforts in advancing knowledge within these dynamic fields.

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Enhancing Email Accessibility for Visually Impaired Individuals: A Voice-Based Email System using Artificial Intelligence

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Abstract

This paper presents an innovative, voice-based email system designed to improve email accessibility for visually impaired individuals. The proposed system leverages Artificial Intelligence and speech recognition technologies to convert speech to text and text to speech, enabling visually impaired individuals to send and receive emails using voice commands. The system offers an intuitive user interface, secure authentication measures, and robust database architecture to ensure seamless and secure user experience. Comparative analysis with traditional email systems reveals the superior functionality and inclusivity of the proposed system. Despite certain limitations, future enhancements promise to further refine the system, paving the way for a more inclusive digital communication environment.

Keywords: Artificial Intelligence; Speech Recognition; Email Accessibility; Visually Impaired; Voice-Based Email System

1 Introduction

With rapid technological advancements and increased internet accessibility, numerous aspects of our lives have become digitalized, including communication [1]. Indeed, communication is one field that has significantly evolved due to technological advancements, making distance a minor factor [2]. One of the most reliable methods for transmitting essential information in this digital age is email [3], a tool used globally. However, not everyone can equally access this beneficial tool. To access the internet and use email, one must be able to see, a prerequisite that poses challenges to a significant number of visually impaired or outwardly impeded individuals globally [4, 5]. Visual impairment restricts individuals from interacting with standard web interfaces that typically require visual input and output [6, 7]. Unfortunately, this means that a significant number of people are effectively cut off from the conveniences of email and the broader web [8–10]. Visually impaired individuals face difficulties in sending and receiving emails, understanding the content provided by email, and using the existing email systems due to their inherent visual interface [10–12]. In the current scenario, a visually impaired person has only one choice for sending an email: they must verbally provide a third person with the entire content of the mail, who then types and sends the mail on their behalf [13]. This practice, however, neither guarantees privacy nor empowers visually impaired individuals, instead reinforcing their dependency on others. In light of these challenges, the authors propose a concept designed to make the digital world, particularly email communication, more accessible to visually impaired individuals. This innovative solution allows a visually impaired person to send and receive emails using voice commands rather than relying on visual devices or keyboards. The proposed system aims to increase societal inclusivity and independence for visually impaired individuals, transforming the way they interact with the digital world.

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Artificial Intelligence (AI) plays a crucial role in making this concept a reality. AI is a technology used to develop intelligent systems and robots that mimic human intelligence [14]. Expert systems, natural language processing (NLP), machine vision, and speech recognition are some applications of AI [15–17] that are particularly relevant to the proposed solution in this study. NLP is the process of understanding and analyzing human language, such as English, by extracting information from keywords, emotions, relationships, and concepts. This technology enables the transformation of voice commands into executable actions, opening a world of opportunities for user interfaces [18, 19]. The proposed system in this article also uses AI to convert speech to text (STT) and text to speech (TTS). Google's Cloud STT service provides developers with a straightforward API for converting audio to text. It includes robust neural network models that recognize over a hundred and twenty languages and variations [20–22]. The TTS engine, conversely, reproduces spoken language from written text, making our system interact with users in a natural, human-like way [23]. This technology allows computers to talk to users, making the system more interactive and user-friendly.

2 Related Work

The proliferation of the internet and digitization has led to an exponential growth in the use of email as a mode of communication [24]. According to the Email Statistics Report of 2014-2018 by a tech market research firm based in Palo Alto, CA, the number of email accounts worldwide has increased from 4.1 billion in 2014 to over 5.2 billion by the end of 2018 [25, 26]. This substantial growth underscores the prevalence of email as a primary mode of communication. However, it's essential to consider the challenges that prevent certain demographics from using this medium effectively. Based on studies conducted by the Vision Loss Expert Group (VLEG), approximately 253 million people worldwide are visually impaired or blind, indicating that a large number of individuals are currently unable to access email [25, 27, 28]. Several existing systems provide email access and management features to users via web services, thereby enhancing email's popularity as a communication medium [29]. However, most of these systems lack voice command or audio capabilities, rendering them unsuitable for visually impaired users. These traditional systems typically present information in textual format which isn't accessible for visually impaired individuals. Although some internet browsers have the capability to play music and video, users must first input textual commands to request such media [7, 30]. This requirement of text-based interaction with web services is a significant impediment for blind users. A noteworthy mention here is the role of screen readers in assisting visually impaired individuals in accessing digital content. Screen readers interpret and read aloud the text displayed on a screen [31]. However, these tools have significant limitations. They read the text sequentially [32], which can be inefficient for complex pages with lots of content. Screen readers can only interpret content provided in basic HTML [33, 34]. Since many modern web pages use advanced languages like CSS, Bootstrap, JavaScript, and others to enhance appearance and usability, screen readers often fail to read and understand these pages [35–37]. Some applications have been developed to aid visually impaired individuals, like mobile apps capable of interpreting and reading data encoded as a barcode on a product [38–40]. Despite being innovative, these solutions are device-specific and not universally applicable, limiting their use. Moreover, they are ineffective in scenarios like accessing emails, which are primarily text-based. The crux of the issue lies in the fact that traditional systems do not offer effective, intuitive, and inclusive solutions for visually impaired users. This gap is what the authors' proposed system seeks to address. Leveraging AI and speech recognition technologies, the proposed system aims to provide a voice-based interface for email communication. This would significantly enhance email accessibility for visually impaired individuals, empowering them to send and receive emails independently. The proposed system innovatively transforms the traditional, visual, and text-based email experience into an auditory one, marking a substantial step forward in inclusivity in the digital world. The rest of the article sections shall delve into the methods and technologies behind the proposed system, detailing how it aims to revolutionize email usage for visually impaired individuals.

3 Methods

The methodology behind the proposed voice-based email system involves several crucial steps ranging from the design of the system's user interface, the architecture of the database, the overall system design, and the development of the mail programming module. The system is subsequently implemented through various features including login, dashboard, send mail, and inbox operations. Finally, the system ensures user authentication and data security.

3.1 Proposed work design

UI Design

The development process begins with designing the system's user interface (UI). This includes the creation of all the web content with which users will interact. An intuitive, user-friendly UI is critical for the success of the application, especially given that it's intended for visually impaired individuals. To make the system universally accessible, the design process employs HTML5 and CSS3 to create a seamless, interactive, and responsive interface.

Database architecture

As the system stores user credentials and email data, a reliable database is a necessity. The architecture of the database includes the construction of various tables designed to store user credentials for authentication purposes and to hold user emails securely. This database architecture serves as the backbone of the system, enabling the efficient storage and retrieval of data.

System design

The system design incorporates all the modules necessary for the framework, including the Text-to-Speech (TTS) and Speech-to-Text (STT) modules, and a Mail programming module. The design ensures that each module complements the others and collectively contributes to the system's seamless operation. In our system, the Text-to-Speech (TTS) conversion is handled by the Google Text-to-Speech (GTTS) service, which provides high-quality and natural-sounding speech output. The working of the GTTS algorithm is depicted in Figure 1 (a) and Figure 1 (b) provides an overview of the system design, showing the connection between different modules in the proposed system.

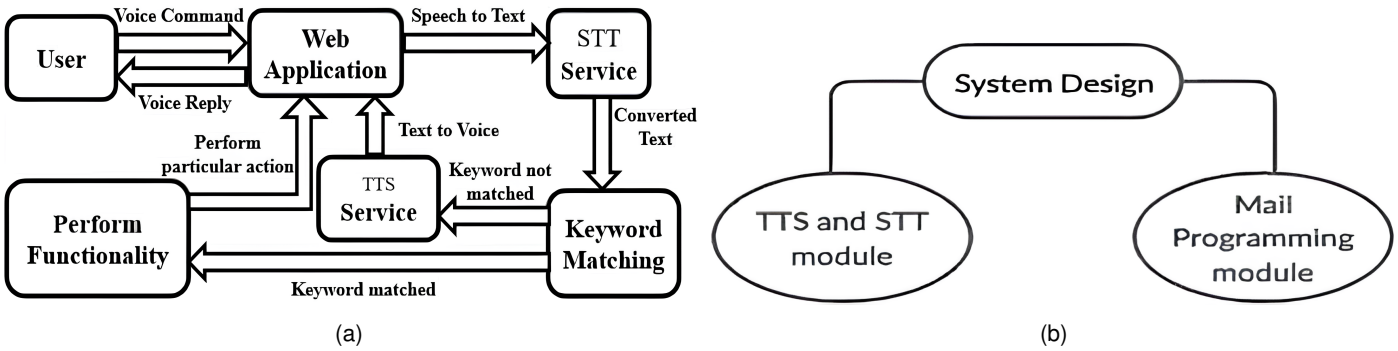


Figure 1: **(a)** Working principle of the Google Text-to-Speech (GTTS) algorithm; **(b)** Comprehensive system design highlighting the interconnections between various system modules.

Mail Programming Module

As email becomes an increasingly important web service, many internet systems utilize Simple Mail Transfer Protocol (SMTP) to send emails from one user to another [41, 42]. SMTP is responsible for sending emails, while the receiving end uses the Post Office Protocol (POP) or Internet Message Access Protocol (IMAP) to fetch the message [41, 43]. Figure 2 (a) presents the architecture of the proposed voice-based email system, illustrating how the various components interact with each other and Figure 2 (b) illustrates how the Simple Mail Transfer Protocol (SMTP) works, which is a key component in the sending and receiving of emails.

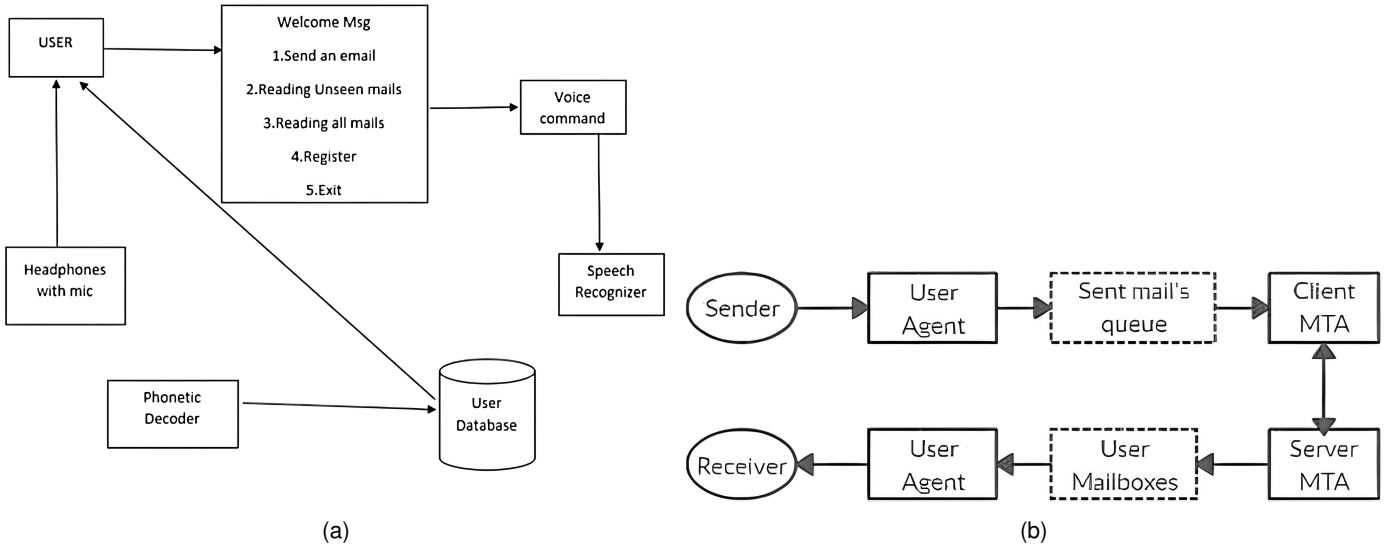


Figure 2: **(a)** Architecture Diagram of Voice-based e-mail system; **(b)** Functioning mechanism of simple mail transfer protocol (SMTP) in email transmission.

3.2 Implementation

The workflow of the proposed system is depicted in Figure 3, which shows how users navigate the application and utilize its features.

Login

Users start by logging into the system using voice commands. The user's Gmail account is the primary method of authentication. If the login is successful, the user is granted access to the system's features. The user interface of the login page, which is the entry point to the system, is shown in Figure 4 (a).

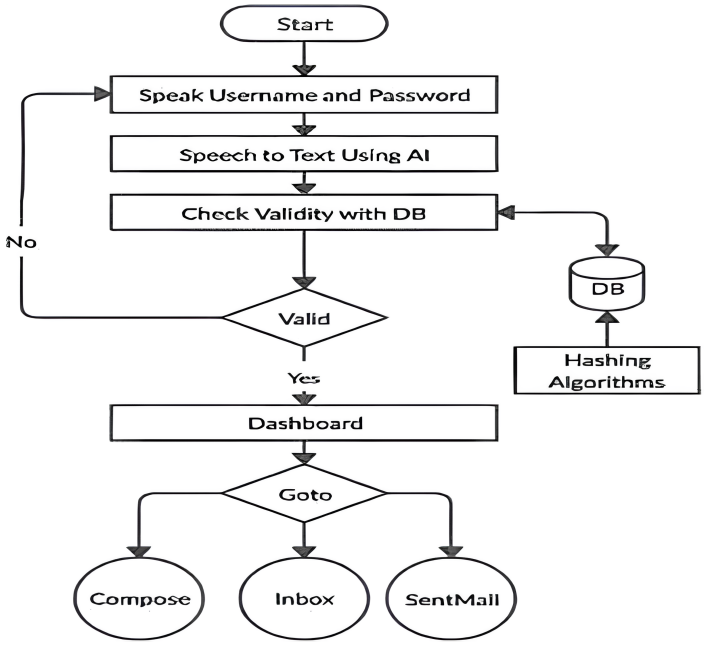
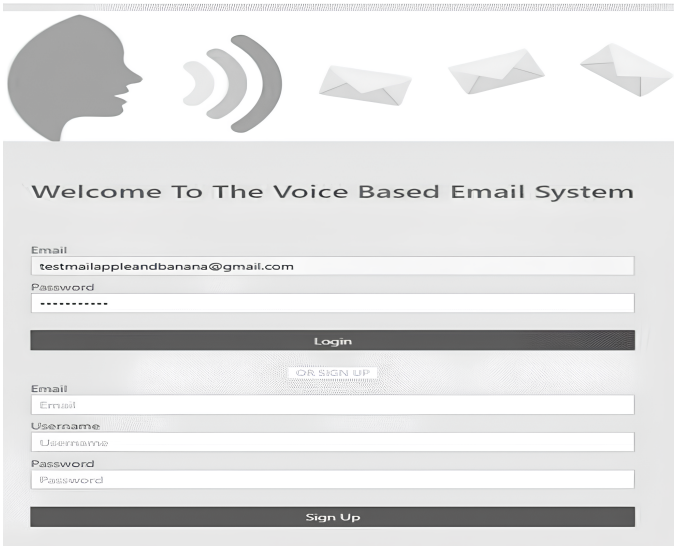


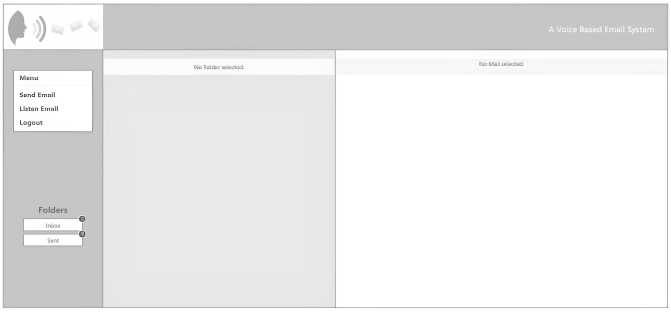
Figure 3: Workflow diagram for Voice-based e-mail system.

Dashboard

Once logged in, the user is directed to the dashboard, which offers various options including 'Inbox', 'Compose New Mail', 'Sent Mail', and 'Trash'. The system performs the corresponding actions when the user issues voice commands. Figure 4 (b) displays the system's dashboard, which offers a variety of options for the user to select using voice commands.



(a)



(b)

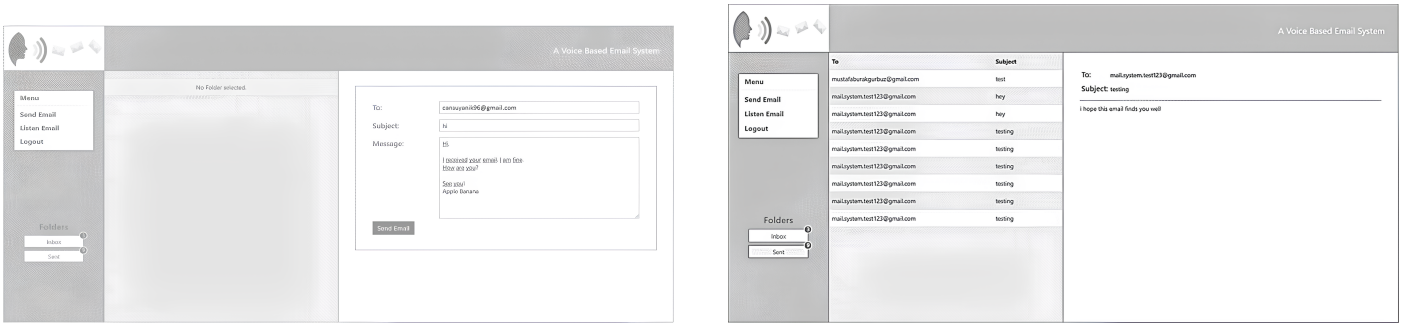
Figure 4: **(a)** User-interface design of the Login page for the designed system; **(b)** Snapshot of the dashboard interface offering multiple options to the user.

Send Mail

When a user wants to send an email, they issue a voice command saying "SEND EMAIL". The system then opens a form where the user fills out necessary details using voice commands. The system re-reads all the details to confirm their accuracy before the user sends the email. The process of composing and sending an email using the designed system is depicted in Figure 5a.

Inbox

The inbox feature reads out new emails to the user. The system alerts the user of any new email received and reads out the senders' names one by one. The user can then specify whose email they want to listen to first. Figure 5b shows the inbox interface of the designed system, where incoming emails are listed.



(a) (b)

Figure 5: **(a)** Demonstration of voice-commanded drafting and sending of emails in the designed system; **(b)** The inbox interface displaying incoming emails in the voice-based email system.

3.3 Authentication and Security

Authentication and security are critical elements of the system [44]. The system implements authentication by requiring users to provide credentials, such as a username and password. These credentials are securely stored in a database and used to verify the user's identity each time they access the application. To ensure security, the system uses a hashing technique. Hashing transforms passwords into a form that cannot be converted back to the original password, significantly enhancing the security of the stored user credentials [45, 46]. The system uses common hashing algorithms like Message Digest Algorithms (MD5) and Secure Hash Algorithms (SHA) [47] to maintain data integrity and security. Figure 6 represents the hashing algorithm used in the system, a crucial component of the system's security measures.

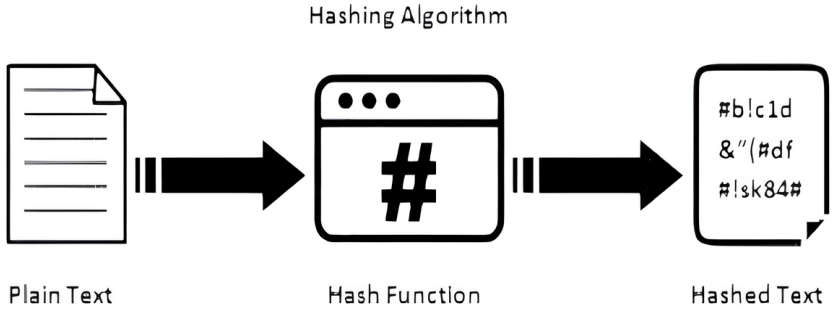


Figure 6: Depiction of the hashing algorithm used for enhancing user data Security in the System.

4 Results and Discussion

The proposed voice-based email system showcases clear advantages over traditional systems. A comparative analysis reveals that the proposed model offers unique features not present in many of the industry's established tools. The model introduces voice command and control, facilitating use by visually impaired individuals, a significant improvement over traditional systems. The model works seamlessly across all email platforms, which is a considerable advantage over other systems that may be platform-specific. In terms of speech-to-text transcription, the Google Text-to-Speech (gTTS) service used in this system provides robust performance. When compared to other services available in the market, gTTS stands out due to its versatility, language support, and accuracy.

The reliability of gTTS in the proposed system contributes to its superior functionality, helping visually impaired users navigate their emails effortlessly. The proposed voice-based email system has a broad scope for future enhancement. Potential improvements could include the integration of various languages and access to additional email categories such as deleted and spam emails. Incorporating a sign-language interpretation module could further increase the system's adaptability, making it even more robust and inclusive. The system finds its application primarily among visually impaired individuals, who can utilize this Android application for a quick and efficient email experience. The system also serves as a beneficial tool for individuals who have difficulty typing or navigating traditional email interfaces. Despite the promising features and applications of the proposed system, some limitations exist. For instance, the system's effectiveness can be hampered if the user struggles with pronunciation, as the system's operation relies heavily on voice commands. At present, the application is limited to working with Google accounts, restricting its use with other email platforms. Furthermore, the system currently lacks fingerprint authentication, which could potentially compromise user security and privacy if they inadvertently disclose their passwords and textual information. Addressing these limitations in future iterations of the system would significantly improve its effectiveness and user-friendliness. The comparison of the proposed voice-based email system with traditional email systems is demonstrated in Figure 7, highlighting the distinctive advantages of the proposed system.

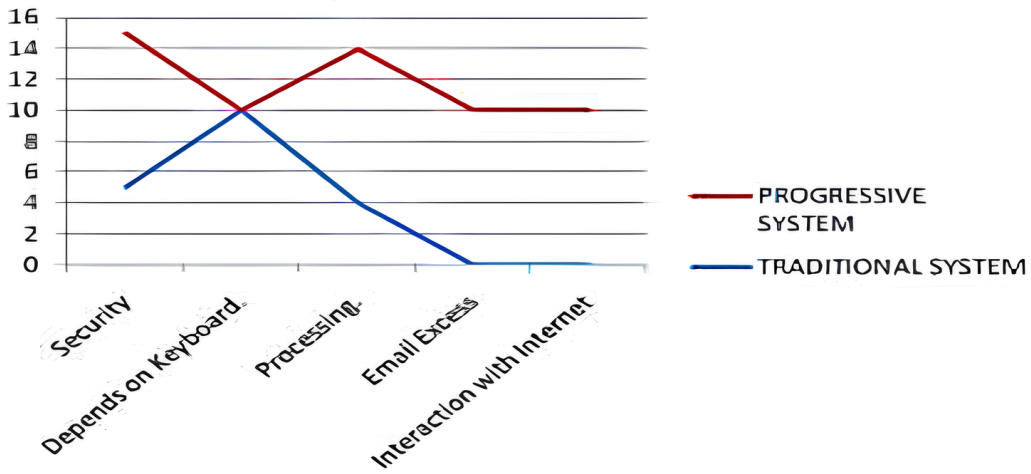


Figure 7: Comparative analysis of the proposed voice-based email system and traditional email systems.

5 Conclusion

The proposed voice-based email system is an innovative and inclusive solution that enhances email accessibility for visually impaired individuals. The system, leveraging Artificial Intelligence and speech recognition technologies, offers an auditory email experience, enabling visually impaired individuals to independently send and receive emails. While traditional systems rely heavily on visual input and output, this proposed system emphasizes the transformation of speech to text and text to speech, making the system user-friendly and practical for visually impaired users. Furthermore, the system effectively eliminates the need for keyboard shortcuts and screen readers, reducing the cognitive load of remembering keyboard shortcuts. With a user-friendly interface and the added value of security features, this system marks a significant step in enhancing the digital experience for visually impaired individuals. Although certain limitations currently exist, future enhancements and modifications hold the promise to make the system more robust and adaptive, leading to a more inclusive digital world.

Declaration of Competing Interests

The authors declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Jaspreet Kaur: Conceptualization, Supervision, Writing- Reviewing and Editing, Project Administration; **Rohit Agnihotri**: Methodology, Data curation, Investigation, Software, Validation; Writing–Original draft preparation.

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CAMEL Analysis of Commercial Banks In Nepal: An Assessment of Financial Soundness

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Abstract

This research paper seeks to perform a thorough assessment of the financial stability and efficacy of commercial banks in Nepal, utilizing the CAMELS analysis framework. The CAMEL framework, incorporating Capital adequacy, Asset quality, Management quality, Earnings capability, and Liquidity position, acts as a structured method for assessing the comprehensive health and resilience of financial institutions. By employing this framework to the commercial banks in Nepal, this study offers crucial insights into the merits and demerits of the country's banking sector. In this investigation, a quantitative, descriptive, and analytical research design is employed to execute the CAMEL analysis of commercial banks in Nepal. The study relies on secondary data, sourced from published financial reports, annual statements, and regulatory submissions of commercial banks in Nepal. A purposive sampling technique is utilized to choose a representative sample of commercial banks in Nepal. CAMEL analysis of commercial banks in Nepal yielded a favorable evaluation of financial stability. The majority of banks showcased commendable performance in various components of the framework, reflecting a predominantly robust and stable banking sector. Nonetheless, certain areas, particularly for smaller banks, necessitate vigilant observation and specific regulatory actions. The outcomes of this study can aid policymakers, regulators, and industry professionals in making enlightened decisions, addressing potential risks, and enhancing the overall financial robustness of the banking sector in Nepal.

Keywords: Asset Quality; CAMEL Analysis; Capital Adequacy;, Commercial Banks; Earnings Capability;, Financial Soundness; Liquidity; Management Quality

1 Introduction

1.1 Background of the study

In Nepal's national economy, the banking sector plays a pivotal role, facilitating financial intermediation, mobilizing savings, and providing credit across diverse sectors. Commercial banks are the principal entities in this sector, tasked with maintaining financial stability, fostering economic development, and aligning with the developmental objectives of Nepal. Given the crucial role of the commercial banking sector, a meticulous evaluation of the health, stability, and efficacy of these banks is crucial. The CAMEL framework is one of the most esteemed methodologies for analyzing and assessing the financial soundness of banks [1]. It is an acronym representing Capital Adequacy, Asset Quality, Management Quality, Earnings, and Liquidity. This model offers a holistic appraisal of a bank's financial stability,

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enabling regulators, policymakers, and stakeholders to discern the strengths and vulnerabilities of commercial banks and pinpoint areas necessitating enhancement [2–4].

By systematically scrutinizing various performance metrics, the CAMEL analysis facilitates a deeper understanding of the stability of individual banks and the banking system at large, providing invaluable insights for decision-making, policy development, and effective oversight. The CAMEL model is deemed invaluable for performance evaluation of banks in India, sometimes serving as a predictive model for bank failures [5, 6]. It is crucial for both the banking sector and regulators. The CAMEL rating approach is recognized as a potent tool for identifying a bank's financial strengths and areas needing improvement, aiding in the formulation of corrective measures to ameliorate weaknesses and enhance overall bank performance [7].

Nepal's banking sector has undergone substantial evolution and expansion in recent times, marked by the inception of new banks, advancements in banking technology, and a heightened emphasis on financial inclusion [8]. However, this expansion also poses challenges, including the imperative to uphold capital adequacy and preserve asset quality. While there have been prior studies on the banking sector in Nepal [9–13], there is a scarcity of comprehensive CAMEL analyses specifically targeting commercial banks in the country. This study endeavors to fill this void by conducting an exhaustive evaluation of the CAMEL components in commercial banks, aiming to furnish a comprehensive understanding of the strengths and weaknesses inherent in these banks, and to identify areas ripe for improvement. By exploring the capital adequacy, asset quality, management quality, earnings, and liquidity of commercial banks in Nepal, this research aspires to provide valuable insights to regulators, policymakers, investors, and researchers, aiding in the formulation of informed decisions pertaining to regulatory actions, risk management strategies, and strategic planning in the banking sector of Nepal. The ultimate objective is to foster a robust and resilient banking sector capable of effectively supporting the economic development and financial stability of Nepal.

1.2 Focus of the study

This study is anchored in the CAMEL framework, encompassing five pivotal components: Capital Adequacy, Asset Quality, Management Quality, Earnings, and Liquidity. The central aim of this research is to appraise the financial soundness of commercial banks in Nepal by scrutinizing these five components. The endeavor is to augment understanding of the inherent strengths and vulnerabilities of commercial banks in Nepal, offering invaluable insights to stakeholders and bolstering the overall stability, efficacy, and performance of the country's banking sector.

1.3 Problem statement

The banking sector in Nepal serves as a pivotal element of the country's economy, and the stability and performance of commercial banks are instrumental in ensuring financial stability and supporting economic development [14]. However, a paucity of exhaustive research exists that specifically analyzes the commercial banks in Nepal using the CAMEL framework. This research paper seeks to bridge this gap by conducting a CAMEL analysis of commercial banks in Nepal. Through the evaluation of the capital adequacy, asset quality, management quality, earnings, and liquidity of these banks, this study endeavors to discern the strengths and weaknesses, potential areas for improvement, and facilitate enlightened decision-making and policy formulation in the Nepalese banking sector. To fulfill the study's objectives, the following research questions will be addressed:

- What is the capital adequacy of selected commercial banks in Nepal, and how does it meet regulatory requirements?
- What is the asset quality of selected commercial banks in Nepal, and what is the level of non-performing loans (NPLs)?
- How is the management quality of selected commercial banks in Nepal?
- What are the earnings and profitability levels of selected commercial banks in Nepal?
- What is the liquidity position of selected commercial banks in Nepal?

1.4 Objectives of the study

This research paper primarily aims to conduct a CAMEL analysis of commercial banks in Nepal. The study seeks to offer a comprehensive assessment of the banks' financial performance and regulatory compliance. Specifically, this study aims to:

- To evaluate the capital adequacy of selected commercial banks in Nepal.
- To examine the asset quality of selected commercial banks in Nepal.
- To assess the management quality of selected commercial banks in Nepal.

- To analyze the earnings of selected commercial banks in Nepal.
- To evaluate the liquidity position of selected commercial banks in Nepal.
- And to present recommendations and implications for policymakers, regulators, and stakeholders.

1.5 Significance of the study

This study, through the execution of a CAMEL analysis on commercial banks in Nepal, aspires to furnish a thorough evaluation of their financial well-being and adherence to regulatory standards. The importance of performing a CAMEL analysis on these banks is underscored by its prospective contributions to a broad spectrum of stakeholders, including policymakers, regulators, investors, researchers, and the entire banking sector, ultimately bolstering the economic progression and financial solidity of Nepal. The insights derived from the CAMEL analysis are invaluable for policymakers and regulators, aiding them in the formulation of pertinent policies and regulations to augment the stability and efficacy of commercial banks. It serves as a cornerstone in establishing regulatory prerequisites and capital adequacy norms, allowing the identification of the strengths and vulnerabilities of commercial banks in Nepal. By scrutinizing elements like asset quality, liquidity, and management efficacy, the analysis acts as a compass for banks in fortifying the overall equilibrium of the banking sector. Investors, in their pursuit of sound investment avenues, lean on meticulous evaluations of banks' financial robustness. The CAMEL analysis offers a holistic appraisal of pivotal performance metrics, empowering investors to make enlightened decisions and reinforcing trust in the banking sector. A profound comprehension of the vitality and performance of commercial banks is pivotal for maintaining the overall harmony of the banking sector. This study can spotlight areas of potential fragility in banks and propose strategies to enhance their robustness, thereby mitigating financial instability risks. It aids commercial banks in discerning their strengths and areas needing improvement, facilitating the creation of effective strategic blueprints. Based on the revelations of the CAMEL analysis, banks can concentrate on refining aspects that necessitate enhancement, optimizing their profitability and operational efficiency. This research paper enriches the existing reservoir of knowledge regarding the banking sector in Nepal, especially in the context of the application of the CAMEL framework. It stands as a significant reference for researchers, academicians, and scholars who wish to delve deeper into the intricacies of the banking landscape in Nepal.

Literature Review

The assessment of the financial soundness of commercial banks has become crucial, especially after the global financial crisis of 2008 [15]. Research by Demirguc-Kunt and Huizinga [16], This study adopts a quantitative, descriptive, and analytical research design for executing the CAMEL analysis of commercial banks in Nepal. Research on the application of the CAMELS framework in emerging economies is extensive. A study by Farhana Afroj [17] on banks of Bangladesh concluded that the CAMELS approach adeptly identified risks and vulnerabilities, aiding policymakers in devising suitable regulatory strategies. Ahsan [18] evaluated the financial performance of selected Islamic banks in Bangladesh using the CAMEL rating analysis approach, concluding that these banks were robust in every aspect of their composite rating systems. Sah et al [19] explored the financial soundness of commercial banks in Nepal using the CAMEL analysis framework, focusing on key indicators related to Capital Adequacy, Asset Quality, Management Quality, Earnings Quality, and Liquidity. Their findings underscored the importance of CAMEL analysis in pinpointing strengths and weaknesses in the banking sector, thus fostering financial stability. Similarly, Keshar Baral [20] emphasized the significance of capital adequacy and asset quality in maintaining banking sector stability through their research using the CAMELS framework. The implementation of CAMELS analysis has profoundly influenced regulatory policies in Nepal's banking sector.Samuel Nkosinathi Dlamini [21] examined the repercussions of applying the CAMELS framework, noting its role in modifying regulatory measures, identifying frail banks, and enforcing corrective actions. Jha & Hui [12] studied the correlation between CAMEL variables and the profitability of commercial banks in Nepal, revealing that Capital Adequacy, Asset Quality, and Management Quality significantly influence bank profitability. Thapa et al. [22] performed a comparative analysis of CAMEL parameters across different commercial banks in Nepal, identifying variations in performance and suggesting areas for enhancement to bolster the overall financial soundness of the banking sector. Acharya et al. [23] explored the nexus between regulatory compliance and financial soundness, emphasizing the importance of adherence to regulatory guidelines for maintaining financial stability in Nepalese banks. The literature suggests that CAMEL analysis is instrumental for evaluating the financial soundness and stability of commercial banks globally and in emerging economies. In Nepal, where the banking sector is integral to economic development, employing the CAMEL framework is vital for risk identification, regulatory measure formulation, and maintenance of the banking system's overall health. However, there exists a research gap in understanding the comprehensive health, performance, and risk profile of commercial banks in Nepal, necessitating further exploration in this domain.

2 Methodology

2.1 Research design

This study employs a quantitative, descriptive and analytical research design to execute the CAMEL analysis of commercial banks in Nepal. The methodology encompasses the gathering and examination of numerical data derived from diverse sources, such as financial statements and regulatory reports of the banks, and facilitates a systematic and objective appraisal of the financial soundness of commercial banks, utilizing established criteria within the CAMEL framework.

2.2 Types of data

This research relies on secondary data, gathered from published financial reports, annual statements and regulatory filings of commercial banks in Nepal. These documents supply data on crucial financial indicators including capital adequacy, asset quality, earnings, and liquidity. Annual reports spanning five years from selected banks have been utilized, covering the fiscal years of 2017/18 to 2021/22.

2.3 Population and sample

Commercial banks, classified as Class "A" banks by the Nepal Rastra Bank, number 20 as of 24 February 2023. These banks constitute the population for this study. Out of these, five commercial banks have been chosen as the sample: Nepal Bank Limited (NBL), Everest Bank Limited (EBL), Nepal SBI Bank Limited (NSBIBL), NIC Asia Bank Limited (NICABL), and Kumari Bank Limited (KBL). A purposive sampling method has been employed to select a representative sample of commercial banks in Nepal, ensuring a diverse representation of both large and small entities within the banking sector.

2.4 Data analysis tools

Descriptive statistics [24] are utilized to summarize and illustrate the key financial indicators of the selected banks, offering a snapshot of the banks' financial performance and stability. Comparative analysis is conducted to evaluate the financial soundness of different banks within the sample, identifying trends, patterns, and disparities in the performance of commercial banks in Nepal. Various financial and statistical tools are employed throughout the research and study process.

2.5 Variables and measurements

In this study, the dependent variable is the "Financial Soundness" of commercial banks in Nepal, representing the main outcome the research intends to measure and assess. The independent variables are the five key components of the CAMEL framework, used to evaluate the financial soundness of commercial banks. These independent variables include [25–30]:

Capital adequacy (CA)

Capital Adequacy, the initial component of the CAMEL analysis, quantifies a bank's capability to absorb losses and sustain financial stability. The capital adequacy ratio (CAR) is a standard metric for assessing capital adequacy, calculated as the ratio of a bank's total capital (Tier 1 and Tier 2) to its risk-weighted assets (RWA) and gmathematically given by Eq. 1.

$$\text{CAR} = \frac{\text{Total Capital}}{\text{Risk-Weighted Assets}} \tag{1}$$

Asset quality (AQ)

Asset Quality, the second component of CAMEL analysis, evaluates the quality and stability of a bank's assets. The non-performing loan (NPL) ratio, representing the proportion of loans not being repaid as agreed, is a standard measure for asset quality and mathematically given by Eq. 2. A lower NPL ratio signifies superior asset quality.

$$\text{NPL Ratio} = \frac{\text{Non-Performing Loans}}{\text{Total Loans}} \tag{2}$$

Management quality (MQ)

Management Quality, the third component, assesses the efficacy of a bank's management in decision-making and strategy implementation. The efficiency ratio is a common metric for management efficiency, calculated by dividing a bank's operating expenses by its total assets, as shown mathematically by Eq. 3. A lower efficiency ratio signifies superior management efficiency.

$$\text{Efficiency Ratio} = \frac{\text{Operating Expenses}}{\text{Total Assets}} \tag{3}$$

Earnings capability (EC)

Earnings Capability, the fourth component, evaluates a bank's ability to generate profits and maintain profitability. Return on Assets (ROA), calculated by dividing a bank's net income by its total assets, is a common measure of earnings. Mathematially, it is expressed as per Eq. 4.

$$\text{ROA} = \frac{\text{Net Income}}{\text{Total Assets}} \tag{4}$$

Liquidity (LQ)

Liquidity, the fifth component of CAMEL analysis, assesses a bank's ability to meet short-term obligations and manage cash flow. The Cash Reserve Ratio (CRR) is a standard liquidity measure, indicating a bank's ability to cover deposits with immediate funds. A higher ratio indicates a superior liquidity position. The CRR can be determined using Eq. 5.

$$\text{CRR} = \frac{\text{Cash and Cash Equivalent}}{\text{Total Deposits}} \tag{5}$$

This research scrutinizes each of the discussed independent variables to comprehend their impact on the financial soundness of commercial banks in Nepal. By analyzing these components, the study aims to offer a comprehensive assessment of the overall financial health and stability of the banking sector in the country.

2.6 Research framework

A research framework serves as a diagrammatic representation, illustrating the relationship between independent and dependent variables [31]. In this context, Financial Soundness is conceptualized as the dependent variable, while Capital Adequacy, Asset Quality, Management Quality, Earnings Capability, and Liquidity are considered as the independent variables and is diagramatically represented by Figure 1.

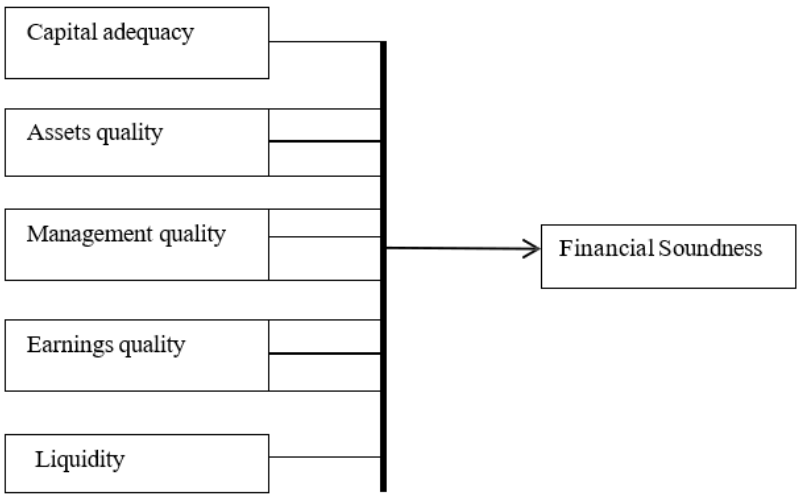

Figure 1: Research framework for the current context.

3 Results

3.1 Capital adequacy assessment

The capital adequacy ratio quantifies a bank's capital, represented as a percentage of its risk-weighted credit exposures. Table 1 delineates the capital adequacy ratios of five selected commercial banks in Nepal from the fiscal year 2017/18 to 2021/22. Referring to Table 1, Nepal Bank Limited (NBL) exhibited a capital adequacy ratio fluctuating between 15.05%

Table 1: Capital Adequacy Ratio of Selected Commercial Banks (In Percentage)

Fiscal Year	NBL	EBL	NSBIBL	NICABL	KBL
2017/18	11.27	14.20	15.15	12.24	13.36
2018/19	16.80	13.74	14.12	13.32	11.75
2019/20	17.01	13.38	14.89	13.50	15.35
2020/21	16.80	12.48	15.55	12.47	13.72
2021/22	15.05	11.89	13.86	13.38	12.63
Mean	15.39	13.14	14.71	12.98	13.36
S.D.	2.43	0.94	0.71	0.58	1.34

Notes: Data derived from the annual reports of the selected commercial banks

and 17.01% over the five fiscal years from 2017 to 2022, averaging 15.39%. Everest Bank Limited (EBL) demonstrated a ratio oscillating between 11.89% and 14.20%, with a mean of 13.14%. Nepal SBI Bank Limited (NSBIBL) had ratios ranging from 13.86% to 15.55%, averaging 14.71%. NIC Asia Bank Limited (NICABL) showcased ratios between 12.24% and 13.50%, with a mean of 12.98%. Lastly, Kumari Bank Limited (KBL) had ratios varying from 11.75% to 15.35%, with a mean of 13.36%.

Summarizing the findings of capital adequacy assessment, the data indicates that all the selected commercial banks in Nepal have sustained their capital adequacy ratios above the regulatory minimum of 11.5% over the last five fiscal years, albeit with some year-to-year fluctuations. Typically, NBL maintained the highest ratios, while NICABL's ratios were the lowest on average.

3.2 Asset quality evaluation

The non-performing loan ratio quantifies the amount of loans that are in default or close to being in default; hence, a lower ratio is preferable. Table 2 presents data on the non-performing loan ratios of five selected commercial banks in Nepal from the fiscal year 2017/18 to 2021/22.

Table 2: Non-Performing Loans Ratio of Selected Commercial Banks (In Percentage)

Fiscal Year	NBL	EBL	NSBIBL	NICABL	KBL
2017/18	3.37	0.20	0.20	0.01	1.05
2018/19	2.64	0.16	0.20	0.23	1.01
2019/20	2.47	0.22	0.23	0.27	1.39
2020/21	2.05	0.12	0.23	0.24	0.96
2021/22	1.83	0.12	0.15	0.07	1.11
Mean	2.47	0.16	0.20	0.16	1.10
S.D.	0.60	0.05	0.03	0.12	0.17

Notes: Data derived from the annual reports of the selected commercial banks.

Nepal Bank Limited (NBL) experienced a decrease in the non-performing loan ratio from 3.37% in 2017/18 to 1.83% in 2021/22. Everest Bank Limited (EBL) maintained a relatively stable ratio, fluctuating between 0.12% and 0.22% during the period. Nepal SBI Bank Limited (NSBIBL) also exhibited stability in the ratio, ranging from 0.15% to 0.23%. NIC Asia Bank Limited (NICABL) began with the lowest ratio at 0.01% in 2017/18 but experienced fluctuations, reaching up to 0.27% in subsequent years. Kumari Bank Limited (KBL) displayed the most variation, with ratios ranging from 0.96% to 1.39%. On average, NBL recorded the highest non-performing loan ratio at 2.47%, while EBL had the lowest at 0.16%.

3.3 Management quality analysis

The efficiency ratio quantifies a bank's cost in relation to its total assets; thus, a lower ratio is preferable. Table 3 presents data on the efficiency ratios of five selected commercial banks in Nepal from the fiscal year 2017/18 to 2021/22. According

Table 3: Efficiency Ratio of Selected Commercial Banks (In Percentage)

Fiscal Year	NBL	EBL	NSBIBL	NICABL	KBL
2017/18	4.25	5.16	6.73	1.83	0.56
2018/19	4.35	5.86	7.57	2.02	1.57
2019/20	5.17	6.14	7.65	2.05	1.49
2020/21	4.21	4.85	6.32	1.54	1.68
2021/22	5.48	5.98	7.12	1.95	1.67
Mean	4.69	5.60	7.08	1.89	1.39
S.D.	0.59	0.56	0.56	0.21	0.47

Notes: Data derived from the annual reports of the selected commercial banks.

to Table 3, Nepal Bank Limited (NBL) exhibited an efficiency ratio fluctuating between 4.21% and 5.48% over the five fiscal years from 2017/18 to 2021/22, averaging 4.69%. Everest Bank Limited (EBL) demonstrated a ratio oscillating between 4.85% and 6.14%, with a mean of 5.60%. Nepal SBI Bank Limited (NSBIBL) had ratios ranging from 6.32% to 7.65%, averaging 7.08%. NIC Asia Bank Limited (NICABL) showcased ratios between 1.54% and 2.05%, with a mean of 1.89%. Lastly, Kumari Bank Limited (KBL) displayed the most variation, with ratios ranging from 0.56% to 1.68%, with a mean of 1.39%. Summarizing the finding, the data indicates that Kumari Bank Limited was the most efficient bank during this period, while Everest Bank Limited and Nepal SBI Bank Limited recorded the highest efficiency ratios, suggesting potential areas for improvement in managing their costs relative to total assets employed.

3.4 Earnings capability examination

Return on Assets (ROA) is a prevalent metric for measuring earnings, representing the ratio of a bank's net income to its total assets. Table 4 provides data on the return on assets ratio of five selected commercial banks in Nepal from the fiscal year 2017/18 to 2021/22.

Table 4: Return on Assets Ratio of Selected Commercial Banks (In Percentage)

Fiscal Year	NBL	EBL	NSBIBL	NICABL	KBL
2017/18	2.41	1.97	1.97	0.97	1.26
2018/19	1.51	1.94	1.94	1.56	1.17
2019/20	1.22	1.42	1.17	1.32	0.76
2020/21	1.33	0.89	0.70	1.09	1.04
2021/22	1.12	1.13	1.07	1.20	1.22
Mean	1.52	1.47	1.37	1.23	1.09
S.D.	0.52	0.50	0.56	0.23	0.20

Notes: Data derived from the annual reports of the selected commercial banks.

Table 4 reveals that Nepal Bank Limited (NBL) had the highest mean return on assets ratio of 1.52% during the period, followed by Everest Bank Limited (EBL) at 1.47%. Nepal SBI Bank Limited (NSBIBL) recorded a mean return of 1.37%. NIC Asia Bank Limited (NICABL) had a mean return of 1.23%, and Kumari Bank Limited (KBL) exhibited the lowest mean return on assets ratio of 1.09%. Examining individual years, NBL achieved the highest return on assets ratio of 2.41% in the fiscal year 2017/18. Both EBL and NSBIBL reached their peak ratios of 1.97% in the fiscal year 2017/18. NICABL attained its highest ratio of 1.56% in the fiscal year 2018/19, and KBL reached its peak ratio of 1.26% in the fiscal year 2017/18. Summaring the findings of earnings capability examination, the data suggests that while NBL secured the highest average return on assets ratio during the period, its performance exhibited more fluctuations, and its ratios declined over the years. Conversely, EBL maintained relatively stable performance, with higher ratios in the recent years.

3.5 Liquidity position assessment

The cash reserve ratio reflects the proportion of funds that banks are required to hold in reserve relative to their total deposits. A higher ratio implies enhanced safety and stability for the bank. Table 5 provides data on the cash reserve

ratio of five selected commercial banks in Nepal from the fiscal year 2017/18 to 2021/22. Nepal Bank Limited (NBL)

Table 5: Cash Reserve Ratio of Selected Commercial Banks (In Percentage)

Fiscal Year	NBL	EBL	NSBIBL	NICABL	KBL
2017/18	9.05	17.75	7.18	24.45	6.85
2018/19	4.06	18.56	6.65	26.05	4.59
2019/20	4.53	14.43	8.89	27.09	3.78
2020/21	4.19	18.15	3.22	20.65	3.72
2021/22	3.49	6.50	3.05	20.30	3.78
Mean	5.06	15.08	5.80	23.71	4.54
S.D.	2.26	5.07	2.57	3.10	1.34

Notes: Data derived from the annual reports of the selected commercial banks.

exhibited a cash reserve ratio ranging from 3.49% to 9.05%, with a mean of 5.06% and a standard deviation of 2.26%. Everest Bank Limited (EBL) displayed ratios between 6.50% and 18.56%, averaging 15.08% with a standard deviation of 5.07%. Nepal SBI Bank Limited (NSBIBL) maintained ratios between 3.05% and 8.89%, with a mean of 5.80% and a standard deviation of 2.57%. NIC Asia Bank Limited (NICABL) sustained the highest ratios among the banks, ranging from 20.30% to 27.09%, with a mean of 23.71% and a standard deviation of 3.10%. Kumari Bank Limited (KBL) recorded ratios between 3.72% and 6.85%, with a mean of 4.54% and a standard deviation of 1.34%. Thus, the result data of liquidity position assessment suggests that Everest Bank Limited and NIC Asia Bank generally maintained higher cash reserve ratios compared to the other banks, signaling superior liquidity and stability.

4 Discussion

4.1 Major findings

The major findings of this study are as follows:

- Regarding capital adequacy, all selected commercial banks in Nepal have maintained capital adequacy ratios above the regulatory minimum of 11.5% over the last 5 years. Nepal Bank Limited (NBL) exhibited the highest average ratio at 15.39%, while NIC Asia Bank had the lowest at 12.98%.
- Concerning asset quality, NBL had the highest non-performing loan ratio, signaling lower asset quality compared to other banks. Everest Bank Limited (EBL) consistently had the lowest ratios, indicating superior asset quality.
- In assessing management quality, the efficiency ratio was utilized to compare costs relative to assets. Kumari Bank Limited (KBL) demonstrated the lowest ratio at 1.39%, indicating optimal efficiency, while Nepal SBI Bank Limited (NSBIBL) had the highest ratio at 7.08%.
- Regarding earnings capability, NBL had the highest mean return on assets ratio at 1.52%, while KBL had the lowest at 1.09%. EBL maintained relatively stable performance with higher ratios in recent years.
- In terms of liquidity, NIC Asia Bank maintained the highest mean cash reserve ratio at 23.71%, indicating superior liquidity and stability, while KBL had the lowest at 4.54%.

4.2 Limitations of the study

The study is subject to the following limitations:

- The accuracy and comprehensiveness of the study may be constrained by the availability of data from published financial reports.
- The generalizability of the study may be limited due to the sample size and selection process. The exclusion of certain banks or the limited size of the sample could affect the overall conclusions.
- Time constraints might limit the depth of the analysis of multiple banks over a specific timeframe.
- The financial soundness of commercial banks can be influenced by external economic factors not accounted for in the CAMEL framework, such as changes in government policies or global economic conditions.
- The study primarily relies on quantitative data, and qualitative aspects like the banks' business strategies or customer relationships may not be fully captured.

- The findings may be specific to the Nepalese banking sector and may not be directly applicable to other regions with different regulatory frameworks and economic conditions.

Conclusion

This research conducted a comprehensive CAMEL analysis of commercial banks in Nepal to assess their financial soundness, focusing on Capital Adequacy, Asset Quality, Management Quality, Earnings, and Liquidity. The findings reveal that the majority of commercial banks in Nepal have maintained satisfactory levels of financial soundness, adhering to the regulatory requirements set by the central bank and demonstrating resilience in challenging economic conditions.

The analysis indicates that most banks have sufficient capital to absorb potential losses, maintaining stability during economic downturns. However, concerns regarding asset quality were noted, particularly for Nepal Bank Limited, emphasizing the need for prudent credit risk management practices to ensure long-term stability. The management quality of the banks was found to be satisfactory, with effective leadership making strategic decisions and implementing sound policies. While most banks have sustained positive earnings, some smaller banks face challenges due to higher operating costs and lower revenue generation. Enhancing operational efficiency and diversifying income sources are crucial for improving overall financial performance. Additionally, most banks have maintained adequate liquidity levels, but some smaller banks show signs of liquidity stress, highlighting the need for improved liquidity management and contingency planning. In conclusion, the CAMEL analysis provides valuable insights into the financial soundness of commercial banks in Nepal, revealing a generally healthy and stable banking sector with specific areas requiring attention. Addressing these areas will contribute to a more robust and stable financial system, supporting Nepal's long-term economic growth and development. Policymakers should leverage these findings to implement measures fostering a competitive and stable banking sector. Continued research and monitoring are essential to ensure the sustained financial soundness of commercial banks in Nepal's dynamic economic landscape.

Declaration of Competing Interests

The authors declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Binod Shah: Conceptualization, methodology, software, data curation, writing—original draft preparation, visualization and investigation, and supervision; **Uday Kishor Tiwari**: Writing, reviewing, and editing.

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Design and Implementation of Multi-Operative Reversible Gate for Even/Odd Parity Generators In Quantum Based Technologies

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Abstract

Quantum technology is graciously budding in nano-communication due to its properties and logical function, having the momentous prosperity of being reversible. It has gained an appeal to future-generation research owing to those sole aspects that may not be explored in the classical realm. A reliable nano-communication system utilizes varied error detection and correction techniques. Beyond low device density, authentic random number generation is a crucial issue in the cryptographic aspects of future communication architecture. To our knowledge, this is the innate study of an intriguing prospect: the design and implementation based on the lower level of power 'even/odd parity generator' using a single multi-operative reversible gate that has been achieved and functionally authenticated in the QCA nanotechnology, likewise in the IBMQ experience allied to quantum-based technologies. This breakthrough in nanotechnology and quantum-based technologies could have significant implications for blooming more efficient, secure communication systems in post-quantum cryptography.

Keywords: Multi-Operative; Reversible Circuit; Even/Odd Parity Generator; Nano-Communication; Quantum Technologies

1 Introduction

'Complementary metal-oxide semiconductor' logic is a highly viable technique for creating computing and communication devices. Quantum-dot cellular automata (QCA) are the preferred surrogate to CMOS technology for making integrated circuits at the nanoscale level. QCA technology presents numerous benefits over CMOS, such as increased circuit densities, quicker processing speed and reduced power usage. In addition, the productive nature of nanotechnology and VLSI fabrication mutually depend on each other's growth. The drive for high-performance digital circuits in the nanoscale is allied to the CMOS paradigm. Quantum-based technology has sparked researchers to explore new approaches to computing and circuit design [1]. It necessitates a reliable and efficient nanostructure, such as QCA, that can replace CMOS and provide faster processing speeds with minimal power consumption at extreme thicknesses[2, 3].

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QCA devices enable current-free information flow [2], resulting in high-density circuits with fast switching speeds at room temperature. It attributes to their low energy usage, dissipation, and density of packaging, with the capability for THz-speed operation [4–6]. QCA was initially shown through Metal-Island use and can be implemented via semiconductor, molecular or magnetic means [7]. QCA devices work on quantum mechanics and charge quantization principles [2, 8]. The quantization of charge is fundamental in quantum mechanics and crucial to its operation. Quantum computing explores this occurrence for new computational devices with potential revolutionary capabilities in information processing [9–12].

This study explored the use of semiconductor-based QCA and quantum computing to enhance security in nano-communication. Our research examines the effectiveness of reversible gates in QCA and quantum computing, with potential implications for secure communication strategies in nanotechnology. The aim is to strengthen secure communication methods during the post-quantum era of cryptography by leveraging quantum effects for information processing and complex computations.

1.1 Preliminaries

QCA basics

In QCA, electron polarizations determine the logic state instead of voltage levels in CMOS technology. The fundamental unit of quantum cellular automata is the QCA cell, which utilizes quantum mechanics principles to enable efficient computation at the nanoscale. This cell contains four strategically positioned quantum dots arranged in a square formation, with two electrons enclosed within. Due to Coulombic repulsion, the electrons occupy antipodal locations in equilibrium. This arrangement of quantum dots serves as a suggested model for quantum computation, as it allows the execution of Boolean logic functions. The intricate states of the quantum dots enable the encoding and processing of information [2–8]. It is akin to traditional cellular automata (CA) and relies on tunneling,' a phenomenon in quantum mechanics, which enables information propagation through the system, allowing non-local interactions and state superposition and applications in computing and cryptography [2–12]. The movable electrons in binary QCA can tunnel between dots and form two stable polarizations, 'P'= +1 (as logic '1') and 'P'= -1 (as logic '0'), following Fig.1 of QCA cell operation [2, 13–19].

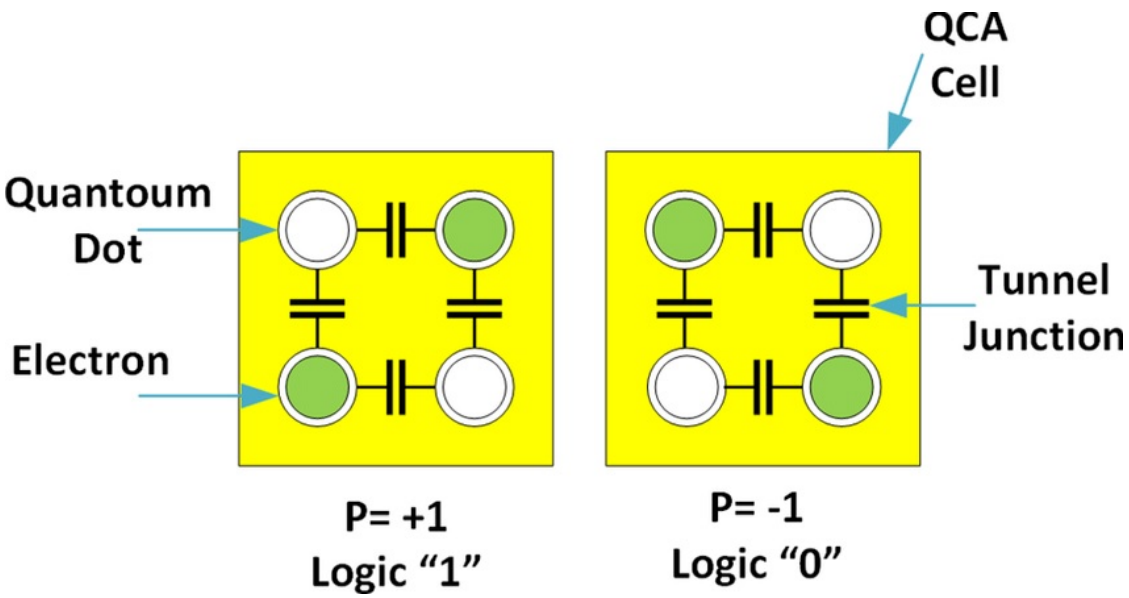


Figure 1: Illustration of two stable stem cell states in a QCA cell using four quantum dots (logic '1' on the left hand and logic '0' on the right) [15].

Coulombic interactions between neighboring cells enable information to flow without electron transfer, resulting in minimal power dispersion. In a series QCA cells, each cell can rearrange its polarized status in accordance with the abutting cell to create the information flow [15–17]. The 'QCA wire', 'Inverter' (I) and 'Majority Voter' (MV) serve as the fundamental and logical building blocks in any QCA circuit design. Their versatile nature facilitates the efficient conception of logical circuits in the QCA framework [3, 8, 18, 19]. The 'MV' acts as a two-input AND gate for any fixed input at the '-1.00' polarization, as a two-input OR gate for '+1.00' polarization [20]. QCA, or Quantum-dot Cellular Automata, is a nanotechnology-based computing paradigm that utilizes the principles of quantum mechanics. In BQCA cell operation, binary information is represented by manipulating and interacting with tiny semiconductor particles called quantum dots. These cells are arranged in a grid-like structure and governed by the laws of quantum physics. The use of QCA in secure nano-communication for post-quantum cryptography has gained attention recently [4, 16–20].

Reversible logic in quantum-based technologies

The primary goal of VLSI is achieving low-power design. With each bit of information lost, conventional irreversible logic circuits release 'KTln2' joules of heat energy, where 'K' stands for Boltzmann's constant and 'T' indicates the absolute temperature throughout the estimation [9]. Bennett's research [10] indicates that KTln2 joules of energy in reversible logic processing cannot be lost. Power-saving reversible logic circuit design is essential for quantum-based technologies, as energy dissipation causes information loss, making it a fruitful area of research [14, 21–26]. The inclusion of reversibility improves QCA effectiveness. Reversible circuit methodology takes precedence in QCA, quantum computing, and DNA computing [16, 27–29]. Quantum technology employs reversible gates like 'Fredkin', 'Toffoli', 'Feynman', and 'Peres Gate' as embellished in [22–30].

Definition 2.2.1:"*If a reversible gate has k inputs and therefore k outputs, Input Vector Iv is mapped with output vector Ov such that mapping is bijective, i.e. the one-to-one mapping between Iv and Ov. The corresponding reversible gate is known as the RLG k*k gate"* [31].

The optimal use of reversible circuits is essential for the efficient operation of quantum computers, requiring physical and logical reversibility. Reversible gates are essential in quantum computing, preserving information by ensuring unique outputs for each input and vice versa. This property allows for backward computations and minimizes energy consumption and heat dissipation in quantum circuits [21–23, 31].

Quantum gates and fundamentals: IBMQ experience

Quantum gates are a crucial component of reversible circuits in quantum computers. Several quantum gates are commonly used in quantum computing, including the "Pauli-X" gate (or 'NOT' gate), "Hadamard" gate, "phase shift" gate, 'Controlled-NOT' gate ("Feynman" or 'CNOT'), "Toffoli" gate ('CCNOT') and the "Swap gate", "RZ gate" and so on [32–35]. Each quantum gate has distinct mathematical qualities that allow it to perform explicit action on qubits on the quantum mechanics platform. Quantum gates can be combined to form complex quantum circuits that enable the manipulation of qubits and the execution of quantum algorithms and circuits. Now, using the equations (1), (2), (3), and (4), look into several widely used gates of quantum computing.

1. The simplest elementary gate is 1×1 'NOT' gate. The "Pauli-X" gate or the bit-flip gate is the quantum equivalent of the classical NOT gate, represented by the unitary matrix, as shown in Eq. (1) [33, 36]:

$$X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} = |0\rangle\langle 1| + |1\rangle\langle 0| \tag{1}$$

2. A quantum gate that generates a uniform superposition of two basis states in one qubit is known as a "Hadamard" gate. It means $|0\rangle$ is converted to $\frac{|0\rangle+|1\rangle}{\sqrt{2}}$ and $|1\rangle$ to $\frac{|0\rangle-|1\rangle}{\sqrt{2}}$. The matrix representation of the 'Hadamard' gate [35, 37–39] is as shown in Eq. (2).

$$H = \frac{1}{\sqrt{2}} \times \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \tag{2}$$

3. The two-qubit "Swap" gate exchanges the states of the two concerned input qubits. The matrix expression is as given by Eq. (3) [34, 37, 38]:

$$SWAP = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

4. 4) A "Rz" gate refers to a diagonal single-qubit rotation operator, which can be implemented in hardware through frame modifications involving z-axis rotations at an angle of 'θ' (measured in radians) [39, 40]. The matrix representation of the "Rz" gate is as given by Eq. (4).

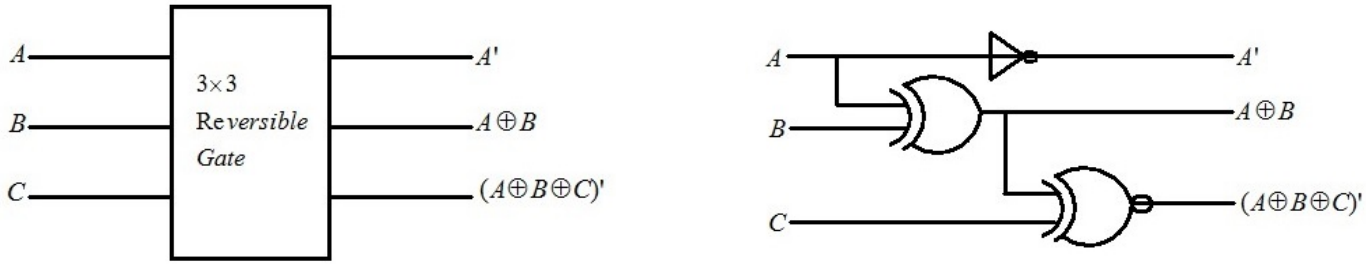
$$Rz(\theta) = \begin{bmatrix} e^{-i\frac{\theta}{2}} & 0 \\ 0 & e^{i\frac{\theta}{2}} \end{bmatrix} \tag{4}$$

Quantum computing uses quantum bits, utilizing quantum mechanics principles, for faster computations, enabling breakthroughs in communication, cryptography, and optimization, which have the potential to revolutionize those fields significantly [32–37]. IBM has developed IBM Quantum Experience (IBMQ) software and cloud-based services to enable researchers, educators, and developers to design quantum algorithms, run them on quantum hardware, and simulate their performance on classical computers [34–38]. Furthermore, IBM Quantum Experience features Qiskit [36, 37], an open-source quantum software toolkit. It consists of various modules with tools to create and manipulate quantum circuits, algorithms implementation, and execution on IBM's devices or simulators. IBM Quantum Experience has been designed to make quantum computing more accessible and facilitate research into the technology's capabilities and limitations.

In practice, QCA and quantum computing increase the security of nanotechnology by optimizing RAM cells, implementing quantum-resistant encryption algorithms, and constructing nanoscale sensors and detectors for secure communication and detection of security breaches or unauthorized access. A few academic efforts have focused on designing multi-operative reversible gates for secure nano-communication circuit applications, including parity generators and parity checkers in quantum-based technologies amid the post-quantum era outlook.

2 The Proposed Designs

The schematic building block and logical representation of the proffered 3×3 Multi-operative Reversible Quantum logic gate (MRQ-gate) are depicted in Fig. 2a and 2b.



(a) (b)

Figure 2: (a) Proposed schematic design of 3×3 reversible gate; (b) Planned logical diagram of 3×3 reversible gate.

The logical diagram illustrates the count of fundamental logic gates (one XOR, one NOT, and one XNOR) used in the proposed design. The output implementation count is needed to evaluate MRQ-gate fabrication complexity. Additionally, the evaluation approach assesses the fabrication complexity of the MRQ-gate by analyzing the output implementation count (as shown in Figure 2b), providing valuable insights into its overall hardware intricacy. The MRQ-gate design has minimal hardware complexity and considers the number of fabrication steps and efficiency by relying only on three fundamental logic gates: XOR, XNOR, and NOT operations within its framework. Indeed makes it a cost-effective potential design for large-scale quantum circuits for implementation in quantum-based Technologies.

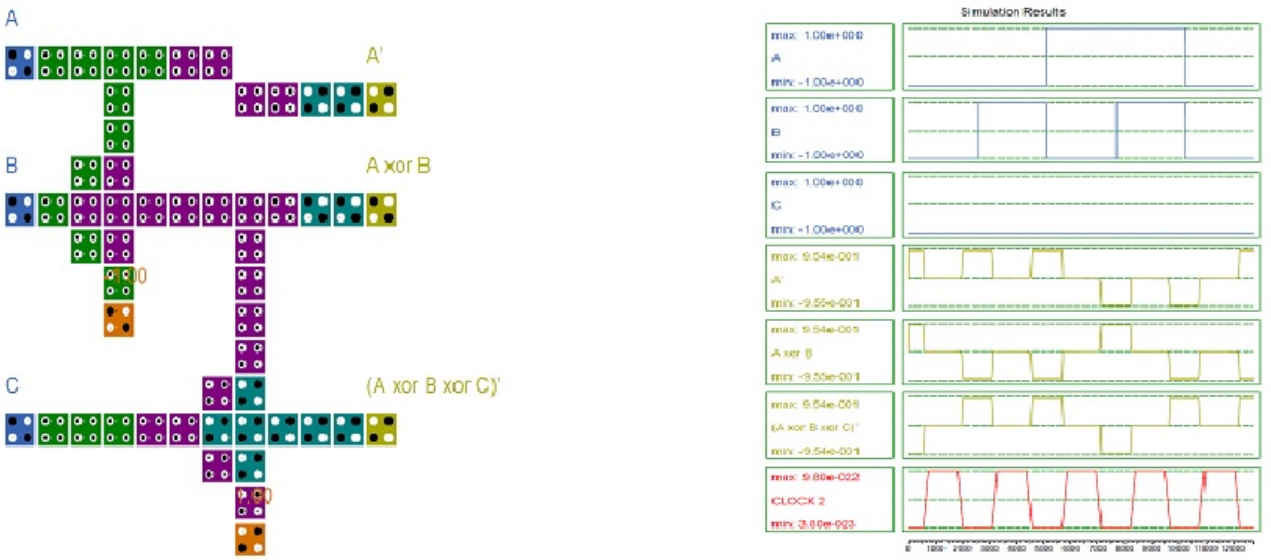
As per the *definition 2.2.1*, a reversible gate has a unique and reciprocal correspondence among its input and output vectors. The MRQ-gate's encoding and input-output combinations are listed in Table 1, establishing and verifying its reversibility. The MRQ-gate mapping function, $IV(A, B, C) \rightarrow OV(A, B, C)$, is tested bijective by examining the correspondence between the input (IV) and output (OV) vectors (as referred to in Table 1). In due course, the QCA schematic layout and its simulation outcomes are exposed in Figures 3a and 3b. Likewise, a quantum computing approach using IBM QISKIT, illustrated in Figures 4a and 4b, can verify and confirm that the MRQ-gate satisfies the criteria for a reversible gate. This property makes the MRQ-gate a potential candidate for implementation in future quantum information processing systems.

Table 1: Truth Table of the Projected 3×3 Reversible Gate: Proof of Reversibility

A	B	C	A'	A XOR B	(A XOR B XOR C)'
0	0	0	1	0	1
0	0	1	1	0	0
0	1	0	1	1	0
0	1	1	1	1	1
1	0	0	0	1	0
1	0	1	0	1	1
1	1	0	0	0	1
1	1	1	0	0	0

2.1 Quantum Technologies and Design Approaches: Simulation Tools and Result

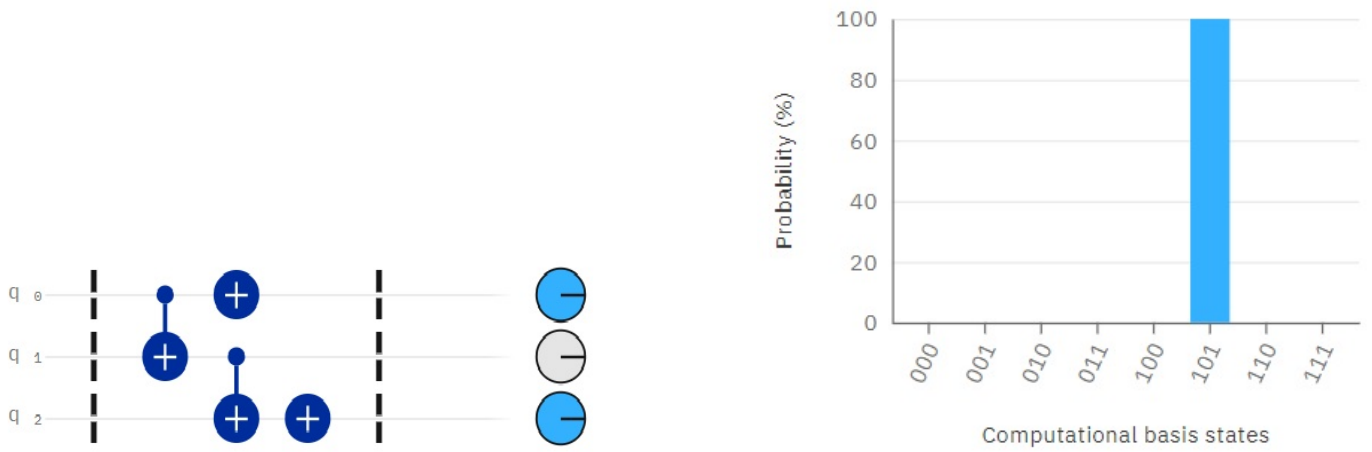
In this section, the design and implementation of our intended Multi-operative Reversible Quantum (MRQ) circuit has been realized in an energy-efficient QCA framework along with IBMQ Experience [36] to authenticate its functionality. Accordingly, the QCA schematic layout adopting QCADesigner 2.0.3 [13] as well as its simulation outcomes are exposed in Figures 3a and 3b. Afterwards, a quantum computing approach using IBM QISKIT design for that proposal computes and illustrated in Figures 4a and 4b



(a) (b)

Figure 3: (a) Schematic QCA layout of the projected 3 × 3 reversible circuit;(b)Simulation results of designed 3 × 3 reversible circuit

These demonstrate the effectiveness of our proposed method in achieving reversible quantum computing with an energy-efficient QCA framework and functional authentication through IBMQ Experience. Overall, these results provide strong evidence for the feasibility and practicality of implementing the intended simple MRQ circuit in real-world quantum computing and open up new possibilities for secure nano-communication applications with improved energy efficiency and functionality.



(a) (b)

Figure 4: (a) The IBMQ schematic layout of the projected 3 × 3 reversible circuit; (b) The probable 3 × 3 reversible circuit's computational output in IBMQ configuration.

3 Application of Multi-Operative Reversible Gate in Quantum-Based Technologies for Even/Odd Parity Generators

This study presents a cutting-edge multi-operative reversible quantum ('MRQ') module that offers an innovative approach and potential applications in quantum-based technologies that are required in designing fundamental components of secure nano-communication systems such as 'Even/Odd Parity bit Generator.' The proposed approach introduces a simple reversible gate that operates at multiple levels that can improve and enhances security for quantum-based technologies at the nanoscale.

3.1 Proposed design and results of even/odd Parity bit generator using MRQ

Now consider 'A', 'B', and 'C' as intended message bits consigned via a communication medium. To generate the parity bit [41–43] 'P_{E-O}', simply one XOR, afterwards one XNOR maneuver, and contrariwise, is recommended. Thus, amid two reversible MRQ gates in a simple cascade connection, a three-bit 'even/odd' parity generator circuit can effortlessly be attained, as shown in Figure 5, where first, the 'MRQ' turns out the XOR of the inputs 'A' and 'B' along with one garbage expense as the complement of input "A.".

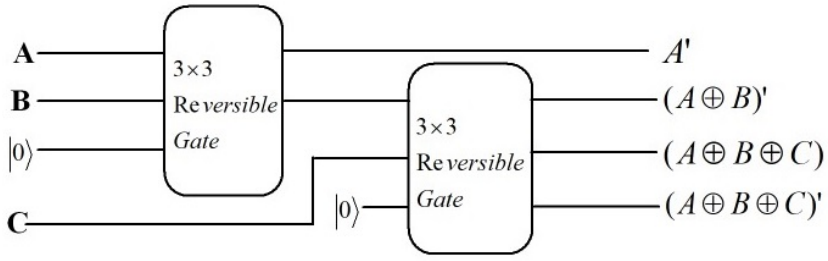
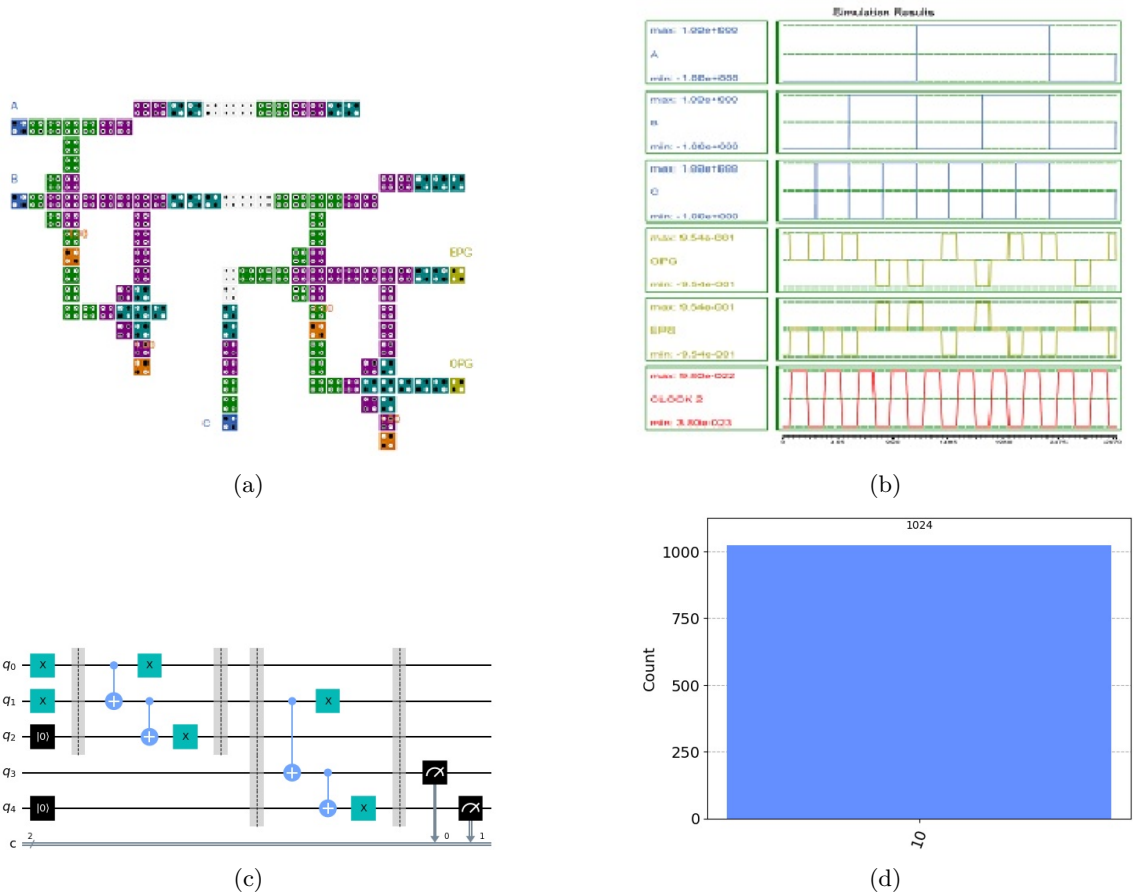


Figure 5: Logical illustration of the proffered 'even/odd' parity bit generator employing two projected multi-operative reversible quantum ('MRQ') modules.

The formed XOR-ed with 'A' and 'B' inputs of the first 'MRQ' is afterwards used as one of the inputs to the second 'MRQ'. The second 'MRQ' gives rise to the garbage value outputs as $(A \oplus B)$', $(A \oplus B \oplus C)$ and $(A \oplus B \oplus C)'$ will be the final corresponding yield bits of the even parity generator (EPG) and odd parity generator (OPG).



(a) (b) (c) (d)

Figure 6: (a) QCA layout; (b) QCA simulation results for the intended 'even/odd' parity bit generator; (c) IBMQ schematic design of the intended 'even/odd' parity bit generator using the projected multi-operative reversible quantum ('MRQ') module; (d) Computational output in IBMQ of the planned 'even/odd' parity bit generator

The logical block illustration and simulation results of the intended 'even/odd' parity bit generator using two 'MRQ' modules have been functionally authenticated in QCA nanotechnology, likewise in IBMQ Experience as portrayed in Figure 5 and Figures 6a, 6b, 6c and 6d. In this work, we have considered the QCA realization concurrently with quantum computing simulation to authenticate the function and performance of the destined 'even/odd' parity bit generator and implementation employing 'MRQ'.

4 Accuracy Analysis and Discussion

This section analyses the accuracy and discusses the study findings and their implications for the current state of research. The proposal demonstrates the potential for producing an 'even/odd' parity bit generator deploying 'MRQ' modules in QCA and IBM Qiskit-like quantum-based technologies. The IBMQ computational output showed perfect accuracy (100%) and matched theoretical predictions for our planned 'even/odd' parity bit generator, as evident in Fig. 6 (d). The terminology 'Even/Odd' also merits this proposal to describe our module's ability to generate both types (even and odd) of parity bits together. This feature is favourable for applications that demand a concurrent generation of even and odd bits without processing delays. The proposed MRQ module-based technology aligns with computational output and theoretical predictions, offering the potential for practical applications in quantum computing. It reliably generates parity bits, reduces errors, and enhances data security, encryption methods, and faster solutions to complex challenges, which could have far-reaching implications for industries relying on data security and computational efficiency. Thus, our projected fruitful schemes in different quantum-based technologies show promising results for reliable and secure nano-communication systems and hold immense gist for multiple applications that meet the growing demands of modern technologies.

However, the proposed design of quantum-based technologies may face limitations and potential hurdles owing to their nanoscale nature, such as defect analysis, fault model development, testing, and the expensive lithography of QCA devices. As another option, scalability, noise, de-coherence, quantum error correction in quantum state measurement, hardware integration, signal synchronization, interconnectivity between components, and high computational cost are challenging tasks open to researchers to achieve robust, practical, fault-tolerant quantum circuits for real-world applications of quantum computing systems [20–22, 28–32, 44–46].

5 Conclusion and Future Works

In conclusion, our projected simple multi-operative reversible gate shows promising results for the effort of many more efficient and secure modules in future computing, nano-communication systems, and cryptographic applications. The research claims that the MRQ-gate design is a practical and cost-effective idea for large-scale quantum circuits since it only necessitates a few simple logic gates, resulting in little hardware complexity.

These findings also provide an opportunity for further academic exploration and development in the post-quantum era. Thus, future works could focus on exploring the potential of this module for large-scale circuits and its integration with other reversible and non-reversible modules to evolve an awe-inspiring 'Network-on-Chip' (NoC) or complex 'System-on-Chip' (SoC)-based nano-communication systems and post-quantum cryptography realization. Depending on the unique requirements of the end users, a single design may be beneficial in a variety of future secure nano-communication modules like "Even/Odd Parity bit Checker", "True Random Number Generator (TRNG)" and many others. It would also be interesting to compare the effectiveness and energy efficiency of the proposed reversible gate to other available choices. Scaling up and optimizing the proposed MRQ module with various quantum technologies could reveal its potential for fault-tolerant computing and more complex quantum tasks.

Declaration of Competing Interests

The authors declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Puspak Pain: Conceptualization, investigation, methodology, and writing - original draft, data curation, formal analysis; **Arindam Sadhu**: Conceptualization, methodology, software, visualization, data curation, writing, reviewing, and editing. **Kunal Das**: Visualization, investigation, software validation, supervision; **Maitreyi Ray Kanjilal**: Supervision; formal analysis, reviewing, editing.

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The Impact of Goods and Services Tax on Sustainability in the Indian Handicraft Sector: A Mini-Review

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Abstract

The implementation of the Goods and Services Tax (GST) in India has significantly influenced the Indian handicraft sector, integral to India's cultural heritage and economy. This mini-review explores GST's multifaceted role in fostering economic, social, and environmental sustainability within this sector. It delves into GST's implications on various aspects of the handicraft sector, including pricing, production, and marketing strategies, and examines the related governmental strategies and policies. Utilizing secondary data, this review reveals how GST has simplified the tax structure, integrated state economies, and created a conducive business environment, promoting sustainable development and innovation in the sector. It underscores the strategic importance of GST in aiding sustainable growth by formalizing businesses, enhancing job opportunities, and encouraging sustainable practices in the handicraft sector. The review also highlights the need for more exhaustive research, incorporating primary data, to gain deeper insights into GST's practical implications on sustainability in the Indian handicrafts sector.

Keywords: Goods and Services Tax; Indian Handicrafts; Sustainability; Taxation Reform; Cultural Industry

1 Introduction

The Goods and Services Tax (GST), introduced in India on July 1, 2017, marked a pivotal reform aimed at overhauling the nation's taxation system [1]. This tax reform has had profound implications on various sectors, including the Indian handicraft sector, a crucial component of India's cultural heritage and economy. The handicraft sector is not only a repository of the country's rich cultural diversity and traditional artistry but also a substantial contributor to employment and the export economy [1, 2]. However, focused analyses on the specific impact of GST on this sector and its sustainability are scarce, necessitating a detailed exploration to understand the repercussions and potential benefits of GST on the handicraft sector. Taxation plays a pivotal role in economic development, and the introduction of GST in India exemplifies this by simplifying the tax structure and reducing the cost of goods and services, benefiting traders, customers, and the government [3, 4]. This has been a significant economic shift since independence, requiring verification of facts following its implementation [5]. Studies propose that tax simplification, such as GST, minimizes the domino effect, fostering a more efficient tax structure and potentially increasing India's economy [6, 7]. The need for GST in India and its potential to contribute to India's economic development is further underscored by drawing parallels with international GST models such as those in Canada, QUEBEC, and Australia [8]. This study aims to bridge the existing gap in literature by scrutinizing the implications of GST on the Indian handicraft sector.

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It seeks to explore how GST has influenced the sustainability, pricing, production, and marketing strategies within this sector and to evaluate the governmental strategies and policies aimed at bolstering the handicrafts industry and promoting sustainable practices within it. The role of the handicraft sector in generating foreign currency underscores its importance in the export market, with its products being sold in over 100 overseas markets, including key markets like Germany, the United States, the United Kingdom, Canada, Japan, France, and the United Arab Emirates [2]. Figure 1 presents a country-wise breakdown of handicraft exports for the year 2020-21, showcasing the global reach of Indian handicraft products. The absence of complex machinery in their production renders these products uniquely invaluable, making them invaluable representations of India's cultural heritage.

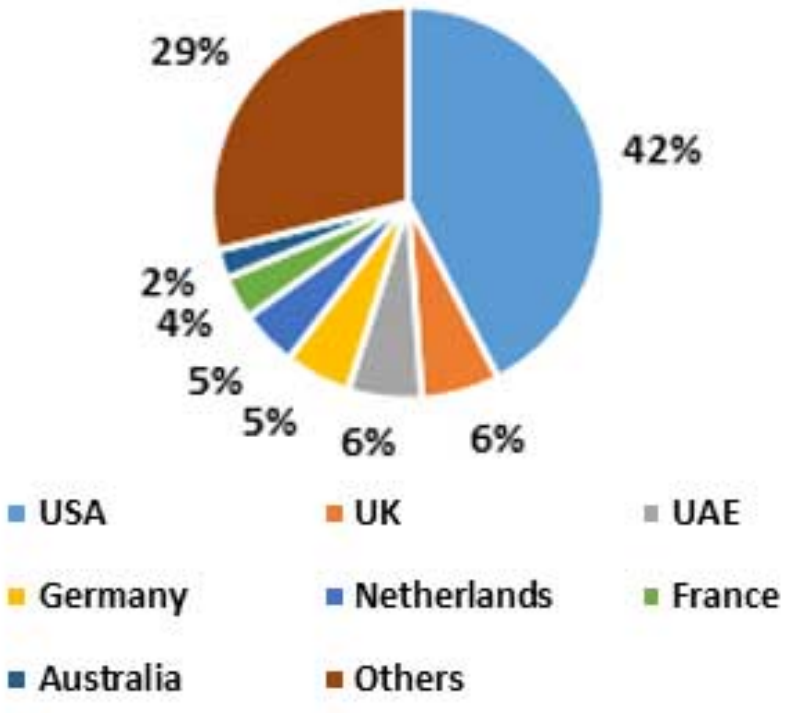

Figure 1: Country Wise Handicraft Exports 2020-21 [9].

To achieve the objectives, this study employs a descriptive and explanatory approach, utilizing secondary data, including information from the Export Promotion Council of Handicrafts and other relevant sources [4, 3]. The analysis focuses on the current state of GST and its implications on the handicraft sector in India, aiming to provide insights into whether GST has been instrumental in fostering sustainable development within the handicraft sector and proposing efficacious policies benefiting all stakeholders.

2 Overview of the Indian Handicraft Sector

India, renowned for its rich cultural heritage and diverse traditions, is a hub for exquisite handicraft products. Each product is a unique expression of specific cultures, reflecting the nation's varied cultural ethos and crafted using local craftsmanship, artistry, and materials [10, 11]. The handicraft sector is crucial for India's economy, being predominantly labor-intensive, decentralized, and a significant contributor to employment and exports [12, 13]. It stands as the second-largest employment generator following agriculture and is pivotal for economic development, contributing significantly to the export economy. This sector is a repository of the country's rich cultural diversity and traditional artistry, and it plays a substantial role in the nation's economic growth. The substantial contribution of the handicraft sector to Indian exports is depicted in Figure 2, highlighting the economic significance of the sector. Handicraft products, encompassing various types such as basketry, leather, metal, pottery, textiles, and wood, are crafted either entirely by hand or with hand tools, bearing unique features that can be utilitarian, aesthetic, artistic, creative, culturally attached, decorative, functional, traditional, religious, and socially significant [15]. Despite having a recognized importance in the export market and a presence in international markets [2], the sector faces specific issues and constraints that threaten the survival of this traditional legacy [16]. Nonetheless, the handicraft sector continues to be a symbol of India's cultural and economic heritage, showcasing a myriad of traditional craftsmanship and artistic expressions.

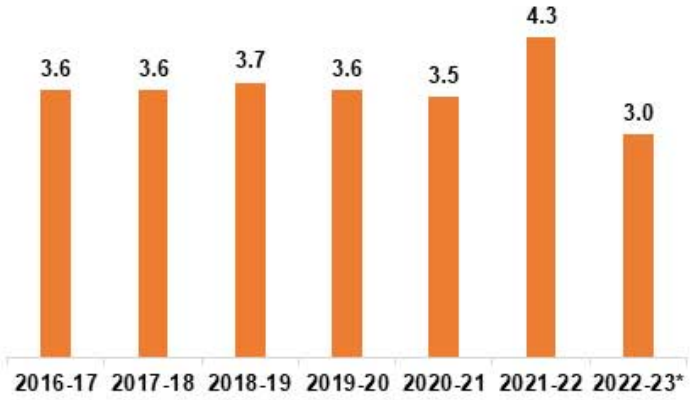

Figure 2: Indian Handmade Export (in US billion dollars) [14].

3 Challenges and Impacts of the Pre-GST Taxation System

Before the implementation of the Goods and Services Tax (GST), the Indian taxation system was multifaceted and intricate, imposing several taxes such as Value Added Tax (VAT), Central Sales Tax (CST), and excise duty at different stages of the production and supply chain [1]. This complexity led to increased compliance costs, lack of transparency, and a cumbersome environment for stakeholders in the handicraft sector, affecting the pricing, production, and marketing strategies within the sector.The contrast between the pre and post-GST tax structures is illustrated in Figure 3, demonstrating the multifaceted nature of the previous tax regime.

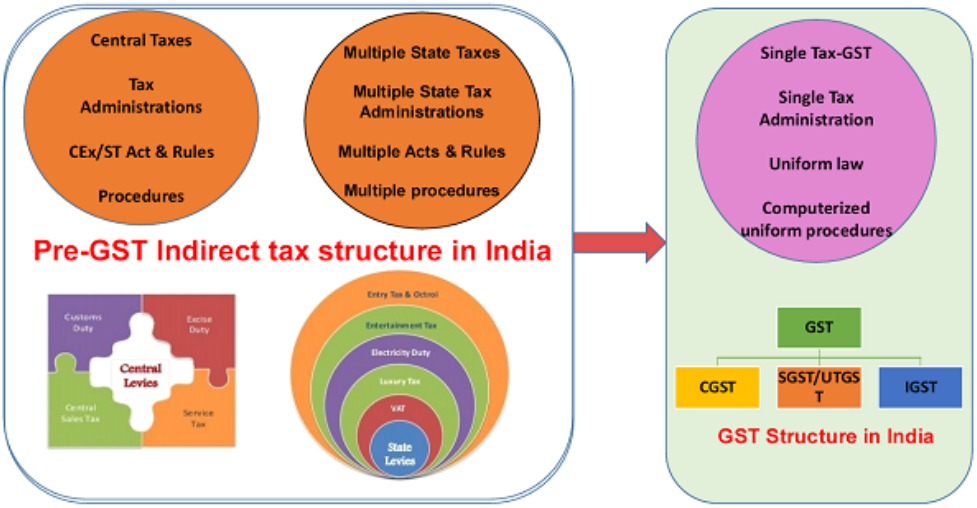

Figure 3: Pre and Post Tax Structure [17]

The cascading effect of these multiple taxes inevitably increased the final price of goods, impacting the competitiveness and sustainability of the handicraft sector. The intricate and complex nature of the pre-GST taxation system significantly hindered the overall growth and sustainability of the handicraft sector, necessitating transformative reform to streamline the taxation process, reduce the burden on the sector, and foster an environment conducive to its growth and sustainability.

4 Government Initiatives and Policies

Recognizing the significance of the handicraft sector in preserving traditional skills and promoting sustainable development, the Indian government has implemented several policies and initiatives [16]. The Comprehensive Handicrafts Cluster Development Scheme (CHCDS) has facilitated the formation of handicrafts clusters to equip artisans with improved infrastructure, technology, and market linkages, enhancing production capabilities and promoting sustainability [18]. Initiatives like the "e-Haat" platform and the National Handicrafts Development Programme (NHDP) are designed to expand the sale of handicrafts through online platforms, reducing middleman involvement and improving artisans' income. The Credit Guarantee Fund Scheme for Micro and Small Enterprises (CGTMSE) provides credit facilities to artisans, enabling investment in crafts and business expansion, contributing to long-term sustainability. Collaborations with institutions like the National Institute of Fashion Technology (NIFT) and the National Institute of Design (NID) offer training and capacity-building programs to artisans.

Geographical Indications (GI) tags protect and promote traditional crafts by ensuring products are region-specific, aiding in the preservation of local craftsmanship and traditions. Initiatives like "Green Crafts" emphasize the use of sustainable and eco-friendly materials in handicraft production, minimizing environmental impact. The Export Promotion Council for Handicrafts (EPCH) works to enhance the export of handicrafts from India, elevating the profile of Indian craftsmen globally and supporting sustainable industry growth [19]. To summarize, the discussed government initiatives and policies encompass various aspects, including skill enhancement, marketing support, and credit facilities, aiming to foster a conducive environment for the growth and sustainability of the handicraft sector.

5 GST's Contribution to Sustainable Development

The Goods and Services Tax (GST) has been instrumental in establishing sustainable development, integrating state economies and creating a conducive business environment [20]. The implementation of GST has simplified taxation, leading to improved tax collections and potentially lowering prices over time, stabilizing the economy [21, 22]. It has encouraged transparency and value co-creation, supporting sustainable logistic performance (SLP) and promoting sustainable practices in public entities and local authorities [23, 24]. The economic impact of GST on the handicraft sector has been multifaceted. It has expanded the handicraft artisan market by creating a unified national market, simplifying the taxation system, and reducing compliance burdens [25]. This has increased market access for artisans, enabling them to reach a wider customer base and potentially increase their earnings. Socially, GST has led to the formalization of many previously informal businesses in the handicraft sector, incentivizing artisans to register their businesses and comply with taxation requirements [1]. This formalization has resulted in improved access to financial services, enhanced social security, and heightened status within society. However, the impact of GST on job creation has been intricate, with arguments suggesting that the compliance burden and initial confusion surrounding GST implementation may have temporarily disrupted the sector's workforce [26, 27]. From an environmental perspective, while GST does not directly address environmental issues within the sector, it creates opportunities for favorable environmental outcomes by promoting the use of sustainable materials and production methods in the handicraft sector [18].

6 Recent Developments in GST and their Impact

The GST Council has made notable revisions and refinements in the handicraft industry, which have had significant impacts on the sector. One of the significant developments is the reduction of the tax rate on numerous handicraft items from 18% to 12% (EPCH). This reduction has likely eased the financial burden on stakeholders in the handicraft industry, potentially fostering growth and development in the sector. Refinements have also been made to the e-way bill system, predominantly used for goods transportation, aiming to streamline the transportation processes and enhance operational ease and efficiency in the handicraft industry [28]. The applicability of refunds under the refined GST processes is detailed in Figure 4, elucidating the enhancements made to the e-way bill system.

Figure 4: Refunds where RFD-01/01A is applicable [29].

These recent developments in GST have enhanced the ease of operations and reduced the tax burden in the handicraft industry, fostering an environment conducive to growth and development. The streamlined processes and reduced complexity are instrumental in promoting the sustainability and overall progress of the handicraft sector.

7 Conclusion

The implementation of the Goods and Services Tax (GST) marked a transformative reform in India's economic landscape, significantly impacting the handicraft sector, a vital repository of the nation's rich cultural diversity and a key economic driver. Before GST, the sector was ensnared in a labyrinth of taxing procedures, characterized by a cascade of taxes and a glaring lack of transparency, which posed numerous challenges and hindered its growth and sustainability. The advent of GST has streamlined the taxation processes, alleviating the financial and operational burdens on the handicraft industry and fostering an environment conducive to its growth and development. The subsequent refinements and adjustments by the GST Council, including the reduction of tax rates and enhancements to the e-way bill system, have further facilitated operational ease and efficiency in the sector. Moreover, the government, recognizing the paramount importance of the handicraft sector, has rolled out a plethora of initiatives and policies. These are aimed at preserving the traditional skills, promoting sustainable development, and enhancing the global presence of the handicraft sector. These initiatives range from the development of handicraft clusters and marketing support through e-commerce to sustainable material promotion and export promotion, significantly contributing to the sector's sustainability and global recognition. In conclusion, the revolutionary changes brought about by GST, along with the supportive government initiatives, have played a pivotal role in mitigating the challenges faced by the handicraft sector, enabling its growth, sustainability, and global recognition, and aiding in the preservation of India's rich cultural heritage. Looking forward, the insights provided by this study open avenues for more nuanced and extensive research. Future studies could focus on a comparative analysis of the impacts of GST across different sectors and its global counterparts. A deeper and more sector-specific exploration into the repercussions of GST and the various government initiatives will offer more profound and comprehensive insights, shedding light on their effectiveness in fostering economic and sustainable development.

Declaration of Competing Interests

The authors declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Rishika Awasthi : Conceptualization, Methodology, Data curation, writing—original draft preparation.; **Moiz Akhtar**: reviewing and supervision. **Farhina Sardar Khan**: writing, reviewing, and editing. supervision.

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Exploring Marine Prospects for Entrepreneurship and Innovation

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Abstract

The marine ecosystem, being both diverse and largely unexplored, presents a fertile ground for innovation and entrepreneurship. This review aims to provide a comprehensive overview of the opportunities available in marine entrepreneurship, focusing on both commercial and research-based avenues. On the commercial side, the review discusses sectors such as aquaculture, global transportation, and eco-tourism, highlighting the need for effective production methods and innovative strategies. In the realm of research-based entrepreneurship, the review explores areas like coral restoration, water desalination, and marine-based product development, emphasizing their potential for sustainable utilization of marine resources. The paper also identifies existing gaps and areas that require further innovation and research, thereby offering a roadmap for young researchers and entrepreneurs. The overarching goal is to promote self-reliance and contribute to the betterment of both nature and humanity through sustainable marine entrepreneurship.

Keywords: Marine System; Marine Entrepreneurship; Innovation Strategies

1 Introduction

The term 'marine' describes a diverse array of ecosystems on Earth. Originating from the French word for sea, the marine ecosystem has traditionally been associated with saltwater bodies, including seas and oceans [1]. Oceans constitute the largest component of the marine environment, covering 71% of Earth's surface [2] and accounting for 97% of Earth's total water [3]. Oceans are further divided into various ecosystems based on zonation. Horizontally, the marine surface water is categorized into neritic and oceanic zones, collectively referred to as the pelagic zone [4]. The neritic zone includes waters near the shore and may consist of ecosystems such as the intertidal zone, rocky shores, and coral reefs [5]. In contrast, the oceanic zone may contain ecosystems like kelp forests. Vertically, the marine system is divided into three major zones based on light penetration: the photic, twilight, and aphotic zones [6]. The photic (0–200m) and twilight (200–1000m) zones are characterized by complete and diffused light penetration, respectively, while the aphotic zone (below 1000m) is devoid of light. These zones host unique habitats for free-floating organisms like plankton and sedentary organisms known as benthos. The aphotic zone is home to deep-sea ecosystems such as hydrothermal vent ecosystems [7].

In addition to these zones, marine ecosystems can also be classified based on salt concentrations, including estuaries, salt marshes, wetlands, and rock pools. Other forms of marine ecosystems, such as mangroves, lagoons, and brackish water ecosystems, also exist but are not easily categorized [8]. A visual representation of these various types of marine ecosystems is provided in Figure 1. Despite its rich biodiversity, only 5% of the ocean has been explored, leaving vast areas yet to be discovered [9].

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Figure 1: Various types of marine ecosystems

Moreover, the extraction of ocean resources, particularly petroleum and oil, has escalated since the onset of industrialization, becoming a significant global enterprise [10]. However, such activities have led to considerable degradation of marine life and ecosystems. Anthropogenic activities, including pollution, further exacerbate the negative impact on marine ecosystems [11]. This situation presents a paradox where marine ecosystems face the risk of destruction by pollution even before they are fully explored. Consequently, there exists a significant opportunity for researchers, entrepreneurs, and innovators to not only explore marine systems for beneficial products but also to develop innovative solutions for the conservation and sustainable management of Earth's most extensive ecosystems. This review aims to summarize various fields of marine entrepreneurship and highlight areas requiring innovation for effective marine ecosystem management.

2 Classification of Marine Entrepreneurship Fields

A considerable amount of work can be undertaken in the marine field. This review proposes to classify this extensive field into two major categories based on market orientation: Commercial-Scale Marine Entrepreneurship and Research-Based Marine Entrepreneurship. A detailed classification of these categories is illustrated in Figure 2.

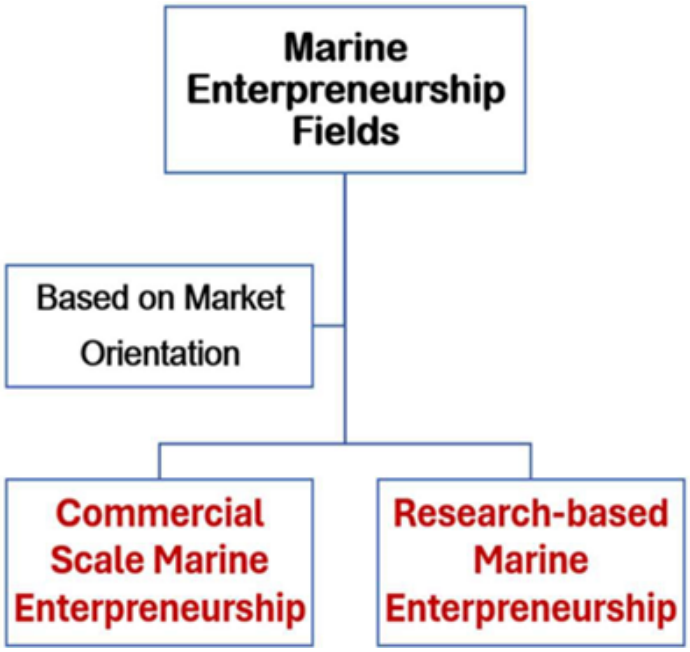

Figure 2: Classification of marine entrepreneurship fields.

2.1 Commercial-Scale Marine Entrepreneurship

Commercial-Scale Marine Entrepreneurship primarily focuses on disciplines that already have a global presence. Significant work is already in progress, and products are being manufactured. A business-oriented mindset is essential for marketing these products to a broader audience. Additionally, innovation is required to establish more effective strategies for the production, processing, and sale of marine products. For example, agar-agar powder, commonly used in making jellies, is already available in the market. In this context, Commercial-Scale Marine Entrepreneurship could focus on strategies to increase sales or reduce production costs. Similarly, seaweed-based essences, perfumes, and cosmetics exist in the market, but their production processes are cumbersome. Groups within this category could work to streamline production and enhance profitability. Common fields within Commercial-Scale Marine Entrepreneurship include aquaculture, the seafood industry, the global transport sector, and tourism.

2.2 Research-Based Marine Entrepreneurship

Research-Based Marine Entrepreneurship necessitates a scientific approach to better exploit marine resources and focus on the restoration of marine habitats damaged over the years due to natural and unregulated anthropogenic activities. A notable example in this category is the Exclusive Economic Zone (EEZ), an oceanic area extending approximately 230 nautical miles beyond a nation's territorial sea. Studies on the EEZ have led to effective strategies for ecosystem protection [10]. Research efforts aimed at simultaneously exploring and protecting deep-sea biodiversity and resources, such as natural gas, also fall under this category. Other fields within Research-Based Marine Entrepreneurship include coral restoration, desalination strategies, and the development of novel compounds from marine microbes.

3 Commercial-Scale Marine Entrepreneurship Opportunities

This section explores various fields under commercial-scale marine entrepreneurship. Figure 3 provides an overview of these fields.

Figure 3: Examples of fields under commercial-Scale marine entrepreneurship.

3.1 Aquaculture

Aquaculture represents an economic human activity conducted in confined areas, aimed at transforming natural aquatic resources into marketable products valuable to society. The scope of aquaculture includes the rearing, breeding, and harvesting of aquatic species such as fish, mussels, and shrimps in controlled environments. The primary objectives are to enhance the growth and survival rates of marine species for both consumption and conservation purposes [12]. Historically, fish were consumed directly from capture. However, it became evident over time that such practices exert stress on ocean ecosystems due to species loss. As a result, aquaculture gained prominence. In the 1990s, the global production of farmed fish was approximately 17 million tonnes. This figure has since increased to around 100 million tonnes [13]. According to 2019 statistics, Asia contributes 92% of many aquaculture products like prawns and shrimps, with China and India being the largest producers [14]. Despite these advancements, aquaculture still accounts for only one-fourth of the fish consumed globally, with the remainder coming from capture [15]. Therefore, there is a pressing need to develop effective strategies to increase production through aquaculture. Additionally, aquaculture water often contains fecal contaminants and nutrient sources, contributing to eutrophication and increasing the risk of harmful algal blooms when released into natural water bodies [16]. Consequently, there is a need for innovative, cost-effective water treatment processes to manage aquaculture water before its release into natural systems.

3.2 Seaweed Culture

Seaweed encompasses all forms of macroscopic algae that flourish in marine water, typically along seashores [17]. Remarkably, seaweeds contribute to 50% of global oxygen production [18]. They are broadly classified into three groups based on pigmentation: Chlorophyceae (green), Rhodophyceae (red), and Phaeophyceae (brown) [19]. Seaweeds have diverse applications, including in the fields of medicine, food, fuel, agriculture, and cosmetics [20]. They are consumed as delicacies, serve as additives in various dishes, and are a rich source of vitamins and minerals. Seaweeds have been shown to reduce the risk of diabetes, cancer, and cardiovascular diseases. They are also used in cosmetic products like face washes, face masks, and anti-aging creams. Furthermore, seaweeds are part of next-generation projects such as organic farming, bioremediation, water mass cleaning, bioplastics, biofuels, and nanotherapies [21]. Seaweed culture involves the cultivation of commercially valuable seaweeds in either natural or artificially induced habitats, such as open oceans or specialized aquatic sites. These sites could be lakes, wells, or areas excavated and filled with water. The water should be non-stagnant, and the ideal temperature should range between 25–30°C. The site should also be protected from heavy rains and winds [22]. Artificial sites must be prepared to be conducive for seaweed growth, which includes the removal of barriers and other vegetation [23]. No fertilizers, pesticides, or insecticides are required for seaweed culture.

Site preparation also involves the collection of materials like nylon threads, digging bars, stakes, and boats [22]. Seaweeds for cultivation can be sourced directly from the sea and propagated vegetatively [24]. Various methods are employed for seaweed cultivation, including the fixed-bottom method, floating raft method, and longline method [22]. Currently, 42 countries, including India, engage in seaweed production. Asia leads in seaweed culture, with China, Korea, and Japan contributing over 80% of global seaweed cultivation [25]. India, with its 7500 km coastline, is a hub for diverse seaweeds with unique potential. Economically valuable species like Sargassum, Porphyra, and Gracilaria have been identified for cultivation along the Indian coastline [26]. Given that many people living near the coastline depend on marine activities for their livelihood, India has the potential to meet global seaweed demand and generate significant revenue.

3.3 Global Transportation

Transportation between countries primarily occurs through three routes: airways, waterways, and land routes. While land routes are not universally applicable, airways and waterways serve as the main options [27]. Airways are often expensive and offer limited capacity due to payload restrictions. Consequently, maritime transportation emerges as the most viable option [28]. Maritime transportation has a long history, dating back to 3200 BCE along the Egyptian coasts. By the 10th century, Chinese merchants had established trade routes. Currently, approximately 55,000 commercial vessels are registered under global maritime shipping industries. In recent years, the Asia-Europe route has seen the establishment of numerous commercial linkages [29]. Maritime transportation is generally classified into four categories based on the type of goods or passengers being transported: passenger vessels, bulk carriers, general cargo ships, and Roll-On/Roll-Off (RORO) vessels. Passenger vessels transport people, bulk carriers handle goods in large quantities, general cargo ships carry lighter weight goods (below 10,000 deadweight tonnage), and RORO vessels are designed for transporting cars and other vehicles [29]. Entrepreneurs and innovators can engage in any form of this global transportation to start a business. However, several challenges require attention, including slow transport services, tracking difficulties, damage during transport [30], and environmental concerns such as oil spills and leaks contributing to marine pollution [31]. There is an urgent need for solutions to make maritime transportation more efficient and environmentally sustainable.

3.4 Eco-tourism Services

Eco-tourism focuses on travel that promotes and supports natural ecosystems, including forests, waterfalls, and oceans [32]. While many travel services offer eco-tourism to wildlife sanctuaries, forests, and hilly regions, only a few specialize in marine-based eco-tourism. Various sources suggest that eco-tourism services present a promising startup opportunity [33, 34]. Additionally, the development of innovative infrastructure designs that minimize environmental impact is a valued sector in this field [35].

3.5 Scuba and Water Sport Centres

Water sports such as swimming, surfing, and scuba diving are popular activities for tourists visiting coastal areas. People are often willing to spend money on these activities, making the establishment of businesses in this sector a viable option. Scuba diving, in particular, has evolved into a multibillion-dollar industry [36]. Entrepreneurs interested in this field can focus on maintaining high safety standards to build a profitable and trustworthy business [37].

4 Research-Based Marine Entrepreneurship Opportunities

This section delves into various fields under research-based marine entrepreneurship. Figure 4 offers an illustrative overview of these fields.

Figure 4: Examples of fields under research-based marine entrepreneurship

4.1 Isolation of Novel Marine Bacteria

Marine systems are renowned for their biodiversity, ranging from the Antarctic blue whale to microscopic marine viruses. These ecosystems also contain small live cells of bacteria and archaea that play a crucial role in the cycling of carbon and nitrogen in the ocean [38, 39]. The ocean surface contains approximately 10^5 to 10^6 cells per ml, while the deep ocean has 10^3 to 10^5 cells per ml [40]. Marine bacteria may belong to various genera such as Pseudomonas, Alcaligens, Flavobacterium, and Bacillus, and can generally be isolated directly from seawater or sediments [41]. Marine microbes typically exhibit characteristics like small size (1–2μm), proteolytic activity, pleomorphism, motility, and slow growth. About 95% of marine bacteria are Gram-negative and predominantly pigmented [7]. These characteristics open avenues for diverse applications, such as the discovery of novel enzymes with higher stability than plant- and animal-based enzymes [42], biosurfactants, and bioremediation [43]. Marine bacteria can also produce pigments; for example, Streptomyces ruber and Vibrio ruber produce red-colored prodigiosin, while Pseudoalteromonas luteoviolacea and Chromobacterium vioaceum produce violet-colored violacein [44]. Research is also needed to formulate new types of culture media and innovative strategies to increase the culturability of marine microbes.

4.2 Coral Restoration

Coral reefs are often referred to as the rainforests of the ocean [45]. Found in approximately 100 countries, they are primarily located in two distinct regions: the Wider Caribbean and the Indo-Pacific [46]. Coral reefs are among the Earth's oldest ecosystems and exist in three geomorphic categories: fringing reefs, barrier reefs, and atolls. They support an extraordinary diversity of species and act as natural barriers to protect shorelines from erosion [47]. At least 500 million people depend on coral reefs for food, coastal protection, and livelihood [48]. However, marine pollution and global warming have led to the continuous degradation and death of coral reefs. Over recent decades, around 20% of corals, particularly in the Caribbean Sea and Southeast Asia, have been severely degraded [49]. Efforts are underway globally to restore corals, but they take hundreds of years to form. Current initiatives include the removal of invasive species that harm corals and the artificial implantation of sponges to maintain coral-dependent diversity [50, 51]. However, more innovative ideas and efforts are needed in this sector. Researchers, entrepreneurs, and innovators are encouraged to contribute solutions to this pressing issue.

4.3 Water Desalination Strategies

The increasing population and depletion of freshwater resources have made seawater desalination increasingly essential. Seawater typically has a salinity of 35 parts per thousand (ppt), whereas drinking water requires a salinity below 0.5 ppm [52]. Various techniques for desalination are in practice, including reverse osmosis, Multi-Stages Flash desalination, Multi-Effect Distillation, electrodialysis, ion exchange, and liquid-liquid extraction [53, 54]. However, these methods are often expensive and may not be affordable for the general public. Therefore, more cost-effective desalination strategies are needed. Innovations in this field include solar thermal-based desalination methods [54] and nanoporous graphene membranes for desalination [55]. Innovators and investors are encouraged to develop practical protocols and cost-effective solutions for water desalination.

4.4 Restoration of Dead Zones

Dead zones are areas in the ocean where biodiversity is almost entirely lost due to complete oxygen depletion [56]. These zones are created when the environment becomes sealed off from the atmosphere, usually in deep ocean waters far from gas dissolution and lacking ocean current flow [57, 58]. Excess fertilizers can lead to hypereutrophic conditions, causing algae to form films on the surface water. When these algae die, the dissolved oxygen is consumed for decomposition, leading to the formation of dead zones [59]. Examples of such zones include the Baltic Sea, Oregon coast, and the Black Sea [60]. Although ongoing projects aim to restore these zones, more effort and innovation are needed to prevent nitrogen-rich runoff into the ocean [61]. Extensive research is also required to identify microbes, plankton, and macro-forms that can help revive dead zones.

4.5 Marine Taxonomists

Taxonomists are individuals who analyze and classify organisms based on their characteristics, placing them into biological groups. The marine system is rich in both micro and macro-organisms, many of which are either newly discovered or yet to be discovered. Proper classification of these organisms will facilitate systematic study and contribute to the understanding of marine biodiversity. Recently, DNA barcoding has been gaining wide attention. Many companies and researchers are developing mobile sequencers that help identify organisms at field sites with minimal samples [62]. Similar software designs and tool developments are also needed to carry out DNA barcoding of these marine forms. Such innovations can make big business and ease the identification of marine life forms.

4.6 Marine-based Product Development

Various marine-origin products are available in the market, including pharmaceuticals, nutraceuticals, and chemicals like agar and alginate [63, 64]. However, numerous products still require exploration and testing before commercialization. For example, bioactive compounds such as Okadaic acid from Gambierdiscus and superoxide dismutase from Porphyridium microalgae are known for their antifungal and antioxidant properties [65]. The constant discovery of marine-based products provides opportunities for entrepreneurs in drug testing, bioinformatics analysis, and animal model studies, as well as for innovators in product synthesis and cost reduction.

4.7 Models to Reduce Marine Pollution

Marine pollution results from the introduction of harmful chemicals or particles into the ocean. Often, potentially toxic chemicals adhere to tiny particles, which are then ingested by marine organisms and move up the food chain [66]. The primary sources of marine pollution include plastics, solid waste, fertilizers, heavy metals, oil, sewage, and radioactive waste, most of which are anthropogenic [67]. Various strategies have been employed to address this issue, such as reducing agricultural runoff, promoting reusable substances [68], raising public awareness, and implementing strict policies [69]. Solutions or clean-up projects in this area can attract significant funding and potentially form lucrative businesses.

4.8 Preparation of Anti-biofouling Agents

Biofouling refers to the undesirable accumulation of various life forms, including microorganisms, plants, algae, and animals, on surfaces [70]. This phenomenon poses significant challenges in marine technology, affecting shipping and industrial aquatic processes. Marine biofouling specifically refers to the growth of marine organisms on immersed artificial structures like ship hulls, jetty pilings, navigational instruments, aquaculture net cages, and seawater intake pipes [71]. The primary taxa associated with biofouling include arthropods, mollusks, annelids, chordates, and seaweeds. Current approaches to prevent and remove biofouling are physical, chemical, and biological. Physical methods involve mechanical removal, chemical methods use materials like silicone elastomers and metals, and biological methods employ metabolites from seaweeds [72, 73]. However, these methods are not entirely convenient and have a limited effective duration. Thus, the development of more effective anti-biofouling agents is needed.

5 Discussion and Future Research

Marine Entrepreneurship offers new funding opportunities and fosters collaborations for expertise and technology to enhance trade cooperation. This sector provides solutions and technologies that support green trades. Tidal devices, underwater robots, automated ships, underwater internet systems, bioplastics from seaweed, artificial intelligence for image analysis, marine compounds for cosmetics, alternative feed sources, and marine-based fertilizers play a crucial role in the global economic progression of the maritime sector [74]. Specifically, in the realm of research-based marine potentials, various renowned institutes are making significant contributions.

These include the Woods Hole Oceanographic Institute and Scripps Institute of Oceanography in the United States, Plymouth Marine Laboratory in the United Kingdom, Institute of Marine Environment and Resources in Vietnam [75], and Institute of Marine Research in Europe [76]. In India, the Central Marine Fisheries Research Institute in Kochi, Kerala [77], CSIR: National Institute of Oceanography in Goa [78], and CSIR: Central Salt and Marine Chemicals Research Institute in Bhavnagar, Gujarat [79] are making advances in marine-based fields. Commercially recognized marine-based companies like ORPC in Alaska [80], Oceaneering Internationals in the USA [81], A.P. Moller–Maersk Group in Denmark, and CMA CGM Group in France [82] also contribute to the sector. Marine Entrepreneurship is rapidly becoming one of the leading and fastest-growing investment sectors globally. Entrepreneurs and researchers entering this field early are likely to reap significant rewards in the near future.

6 Conclusion

The marine system is a vast and complex domain that offers a plethora of opportunities for entrepreneurship, innovation, and research. As this review has highlighted, the scope for marine entrepreneurship is broad, ranging from commercial scale ventures such as aquaculture and global transportation to research-based initiatives like coral restoration and water desalination strategies. Effective production methods and innovative strategies are not merely optional but essential for the development of sustainable and productive marine products and services.

Marine entrepreneurship is particularly significant for standardizing best practices across various sectors within the marine ecosystem. This standardization is crucial for ensuring that all stakeholders operate according to a common set of trade and environmental guidelines, thereby promoting sustainability and ethical practices. Furthermore, marine entrepreneurship has the potential to be a game-changer for developing countries. It can serve as a robust source of revenue, create employment opportunities, and contribute to foreign exchange earnings, thereby having a multiplier effect on economic development.

In summary, the marine system is a fertile ground for entrepreneurial activities that can yield both economic and environmental benefits. As the sector continues to grow, it is imperative for entrepreneurs, researchers, and policymakers to collaborate closely. Such partnerships will be key to unlocking the full potential of marine resources while ensuring their sustainable management for future generations.

Declaration of Competing Interests

The authors declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Shwetakshi Mishra: Conceptualization; writing—original draft preparation, reviewing, and editing

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A Critical Review of Mechanical and Wear Resistance Characterizations on Developed Aluminium Matrix Composite Reinforced With MgO Particulates

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Abstract

Aluminium matrix composites (AMCs) have garnered significant attention due to their extensive applications in diverse engineering sectors, including aerospace, automotive, marine engineering, and mineral processing. The incorporation of ceramic reinforcements, such as oxides and carbides, into these composites substantially augments their mechanical attributes. These ceramic materials contribute to the enhancement of various properties, including strength, hardness, and durability. Moreover, the improved thermo-mechanical characteristics, wear resistance, sustainability, and cost-efficiency render these composites highly versatile. Specifically, composites formulated through the amalgamation of aluminium and magnesium oxide (MgO) particulates offer an optimal balance between lightweight construction and a high strength-to-weight ratio. The primary objective of this review study is to conduct a comprehensive analysis of AMCs reinforced with MgO particulates. This analysis encompasses the methods of synthesis, the mechanisms contributing to material strengthening, and a focused examination of the impact of MgO reinforcement on mechanical and wear resistance properties.

Keywords: Aluminium Matrix Composites, Magnesium Oxide, Reinforcement, Mechanical Properties, Wear Resistance

1 Introduction

Aluminium, the most abundant metal, exhibits a plethora of desirable attributes such as malleability, light weight, and excellent corrosion resistance [1, 2]. Aluminium alloys primarily consist of aluminium, augmented with additional elements like copper, iron, silicon, magnesium, and zinc [3, 4]. These alloys are characterized by their lightweight nature and resistance to corrosion [5]. Rohatgi et al. [6] highlighted the versatility of aluminium alloys, which come in various tempers and serve as a broad range of manufacturing materials. Aluminium alloys are categorized into different series based on their alloying elements and properties. For instance, 1xxx series alloys are composed of high-purity aluminium, while 2xxx series alloys are copper-reinforced and exhibit considerable toughness. The 3xxx series contains manganese and offers excellent workability and strength. The 4xxx and 5xxx series are alloyed with silicon and magnesium, respectively, and possess good weldability and corrosion resistance. The 6xxx series includes silicon and magnesium, and the 7xxx series is primarily zinc-based, offering excellent strength and higher ductility [7, 8]. The burgeoning interest in Aluminium Matrix Composites (AMCs) is primarily focused on these aluminium alloys [9]. Various forms of ceramics, such as fibers, particulates, or whiskers, are used for reinforcement.

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Among these, particulate-based AMCs have gained prominence due to their enhanced mechanical properties, including improved microhardness, strength, and wear resistance over pure alloys [10, 11]. Factors such as the method of synthesis, size, shape, and chemical affinity between the matrix and reinforcement materials influence the microstructure and properties of AMCs [12]. Heat treatment techniques, such as aging, are employed to optimize the mechanical properties of these alloys [13]. The formation of strong chemical bonds at interfaces and the wetting of reinforcement by melted materials are considered crucial phases in AMC production [14]. Magnesium Oxide (MgO) serves as an exemplary reinforcement due to its wide range of refractory properties, excellent corrosion resistance, and thermal conductivity [15–17]. AMCs reinforced with ceramic particles exhibit superior mechanical properties compared to the base alloy [18]. These composites are characterized by low density, high microhardness, enhanced strength, and excellent wear and corrosion resistance [19]. Applications of Al-MgO based composites span various industries, including electronics, automotive, and aerospace, owing to their unique advantages [20]. Previous studies have primarily focused on aluminium as the matrix material, exploring its lightweight nature, environmental resistance, and generous mechanical properties [21]. Extensive research has been conducted in this domain over the past decades, as advancements in composite behaviors involve the mixture of more than two materials without amalgamation effects [22]. To evaluate the mechanical properties of various AMCs, common approaches include the rule of mixtures, microhardness testing, tensile strength testing, and wear resistance testing [23]. However, fully harnessing the potential of MgO-reinforced AMCs remains a challenge due to factors like inhomogeneous dispersion properties of the reinforcements, cost considerations, and the high demand for the resulting material's desirable properties.

2 Fabrication Methods

This review aims to shed light on the enhancement of mechanical properties, such as microhardness, tensile strength, and compressive strength, as well as tribological performance, notably wear resistance, through the incorporation of MgO particles. The focus is primarily on the fabrication techniques of Aluminium Matrix Composites (AMCs), specifically powder metallurgy and stir casting methods [24–26].

2.1 Processing Methodology

AMCs can be manufactured through various states: solid [24], liquid [25], and vapor [26]. Solid-state methods are categorized into powder metallurgy, which involves powder blending and consolidation, and foil diffusion bonding, which employs long fibers to form a matrix [27]. Liquid-state methods include electroplating and electroforming [28], stir casting [29], pressure infiltration [30], squeeze casting [31], spray deposition [32], and reactive processing [33]. Semi-solid state processes involve semi-solid powder processing, while vapor deposition methods include physical vapor deposition [34, 35]. Additionally, in situ fabrication routes are also employed for AMC production [36]. Liquid-state manufacturing routes are popular due to the effective distribution of particulates in the melted metal [37]. These methods are cost-effective, with stir casting, squeeze casting, and pressure infiltration being the most commonly used [38]. On the other hand, solid-state techniques like powder metallurgy (P/M) are also prevalent [39]. AMCs are primarily developed either through Liquid Metallurgy (L/M) or P/M routes. Stir casting is a favored L/M method, offering an efficient way to produce modern composites at a low cost [40]. Conversely, the P/M method provides a good distribution of particles in the pure alloy and has the advantages of high tolerance and minimal need for secondary machining processes [41]. Sahoo et al. [42] outlined the three crucial steps in the P/M process: blending or mixing, compaction, and sintering. Stir casting is frequently employed due to its cost-effectiveness and suitability for mass production [43]. The selection of appropriate process variables, such as stirrer speed and pouring and pre-heated temperatures, is crucial for synthesizing high-quality composites [44]. Hashmin et al. [45] emphasized that the cost of developing AMCs using the stir casting process is significantly lower compared to other methods. Owing to its flexibility, usability, and commercial viability, stir casting remains the most extensively researched method for AMC production.

2.2 Stir Casting Technique

The stir casting process is employed for the fabrication of innovative components. Initially, the base matrix is superheated above its melting point and then cooled to a temperature lower than the liquidus to maintain the mechanism. Concurrently, preheated particles are introduced into the slurry and mixed with the matrix alloy using a mechanical stirrer. This stirring can be performed on a continuous or semi-continuous basis. The slurry temperature is then elevated to reach a fully molten state, with stirring continuing for an average duration of 5 minutes at speeds ranging from 300 to 550 revolutions per minute. Subsequently, the molten material is superheated once more before being poured into a permanent mold to achieve the desired component shape, as illustrated in Figure 3 [46]. Composites reinforced with particles have been found to exhibit significant improvements in high-temperature properties, as studied by Nripjit et al. [46]. On the other hand, in situ methods for AMCs involve the formation of reinforcement particles within the aluminum matrix during the fabrication process. This approach enhances particle distribution and interface bonding but may require additional steps or specialized materials. Consequently, the overall cost could be impacted when compared to more conventional methods like powder metallurgy or stir casting.

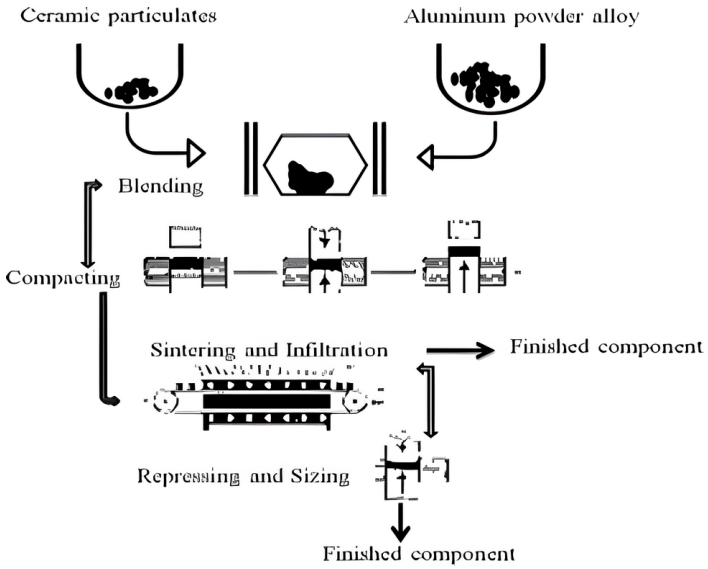

Figure 1: Powder metallurgy method.

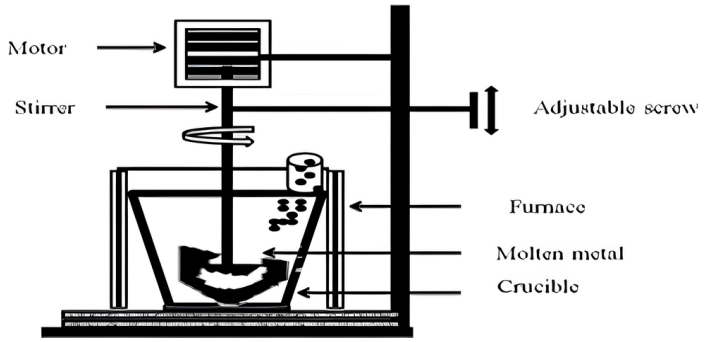

Figure 2: Stir casting method.

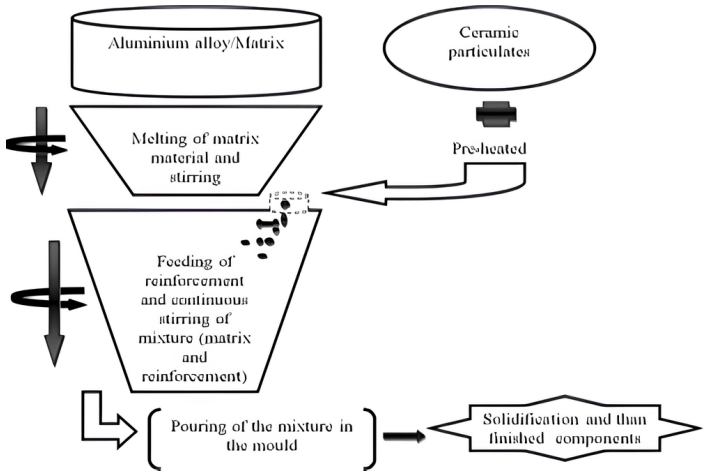

Figure 3: Stir casting procedure.

3 Mechanical Properties

This section aims to investigate the mechanical properties of Al-MgO based composites, which have garnered considerable attention for their potential to improve material attributes. The current study builds upon the extensive body of research in this area, with the intent of contributing new insights. Future research directions that could extend the current findings are also outlined. Various tests have been conducted to evaluate the mechanical properties of metal matrix composites, which utilize aluminum as the base metal and ceramic materials such as Al_2O_3, SiC, and MgO as reinforcements. A significant reduction in grain size has been observed both before and after the addition of reinforcement [47]. In the present study, A356.1-based composites with varying concentrations of MgO nanoparticles (1.5, 2.5, and 5 vol.%) were fabricated at different casting temperatures (800°C, 850°C, and 950°C) using the melt stirring method.

The results indicate that increasing the volume percentage of MgO nanoparticles initially enhances the bulk density of the samples, peaking at 2.5% MgO for all three casting temperatures. This suggests an optimal combination of MgO content and casting temperature may exist for maximizing bulk density while minimizing agglomeration and pore formation. In this context, the highest density was achieved at 850°C [48]. Furthermore, AA 5050/MgO nanoparticle composites with varying volume fractions of MgO (10, 20, 30%) were synthesized using the stir casting process. The tensile strength of the composite was found to decrease with an increase in MgO content, and matrix fractures occurred in composites containing a high volume fraction of 30% vol. MgO [49].

This section also elaborates on the mechanical properties of various aluminum-based composites reinforced with MgO and other materials. For instance, AA 6061 hybrid composite samples were synthesized via the stir casting route, incorporating 1% and 2% wt of Al_2O_3 and MgO. These reinforced composites exhibited notable improvements in microhardness and Ultimate Tensile Strength (UTS) compared to pure AA 6061 [50]. Similarly, A356/MgO-based materials with varying MgO volumes (5, 10, 15, 20%) demonstrated a gradual enhancement in mechanical properties. Specifically, Brinell hardness values ranged from 80.60 to 110.22 BHN, and UTS values increased from 264.96 to 316.11 MPa. Additionally, toughness values ranged from 6.37 to 12.29 J [51]. Another study by Muharrem Pul in 2013 focused on Al-MgO composites with 5, 10, 15% reinforcement. The Brinell hardness values of these samples increased to 50.2, 52.1, 56.4 HB, although the rupture strength values decreased with increased MgO content [52]. Furthermore, Al/MgO composites with 5, 10, 15% reinforcement by volume showed an increase in porosity values (3.99, 4.16, 4.42%). Despite this, the effective thermal conductivity of these composites increased [53]. ZTA/Zirconia toughened alumina composites were also studied, incorporating a 4/1 ratio of Al_2O_3 and aluminum alloy (YSZ). These composites, reinforced with 0.2-0.9 wt.% MgO, exhibited densities ranging from 4.32 to 4.47 g/cm^3 and Vicker hardness values between 1635 and 1694 HV. However, the fracture toughness values decreased from 3.8 to 3.02 MPa-m$^{1/2}$ [54]. The literature consistently suggests that MgO reinforcement enhances both the mechanical and wear resistance properties of composites. These quantitative findings underscore MgO's potential to improve key material properties, making it valuable for various industrial applications. The enhancements in tensile strength, modulus of elasticity, and other mechanical properties indicate the potential for improved structural performance, leading to stronger and more durable materials.

Table 1: Mechanical behaviors of various MgO reinforced composites.

Aluminum alloys	Reinforcement (MgO)	Method	Mechanical properties	Summarized	Reference
AA 7075	5% and 10% (Nanoparticulates)	Stir casting	Brinell microhardness: 92.07 HB, Tensile Strength: 137.042 N/mm^2	Microhardness and tensile strength enhanced with MgO	Prasad et al., 2017 [55]
Pure aluminum	MgO (0.5, 1, 2, 3 wt.%)	Powder metallurgy	Relative Density: Cu+0.5wt.%MgO 91.52%	Relative densities decreased and microhardness increased with MgO	Gozde et al., 2016 [56]
A 356	MgO 1.5, 2.5, 5 vol.%	Stir casting and Powder metallurgy	Brinell microhardness varies	Microhardness and compressive strength improved with MgO	Abdizadeh et al., 2014 [57]
A 356	MgO (0, 5, 10, 15, 20 vol.%)	Stir casting	Brinell microhardness: 75.33 HB, Tensile strength: 232.23 MPa	Increase in microhardness, tensile strength, and toughness with MgO	Kumar et al., 2016 [58]
A356.1	MgO (1.5, 2.5, 5 vol.%)	Powder metallurgy	Brinell microhardness: About 45 HB	Composites containing 5% MgO showed maximum strength	Baghchesara et al., 2012 [59]
Pure aluminum	MgO (various sizes)	Vacuum Infiltration	–	Fracture strength increased with particle size	Calin and Citak, 2018 [60]

4 Tribological Properties

This section discusses the tribological properties of various aluminum-based composites reinforced with MgO and other materials. For example, AA 2219/MgO/Graphite (Gr) hybrid composites were manufactured using melt stirring. The weight content of MgO varied from 0.5%, 1%, to 1.5%, while the graphite content was consistently maintained at 1%. The wear rates of these composites were significantly influenced by MgO particles and were dependent on load, sliding displacement (SD), and speed. Optimal conditions resulted in a wear of 143.28 μm, confirmed by a test that yielded 148-μm wear [61]. AA LM13-MgO composites were synthesized via the stir casting process, with MgO reinforcement ranging from 2–10 wt.%. The wear rate decreased with increasing MgO content, under test conditions varying from 20 to 60 N load at a constant speed of 3.456 m/s [62]. Further, Al (ENAW1050A)/MgO composites with 5–15% reinforcement exhibited varying wear behavior. The wear test was conducted under loads ranging from 10–30 N at a sliding speed of 0.2 m/s. The hardest sample, with 15% MgO reinforcement, exhibited the most wear, while the Al/5% MgO composite showed the least wear under a 10 N load [63].

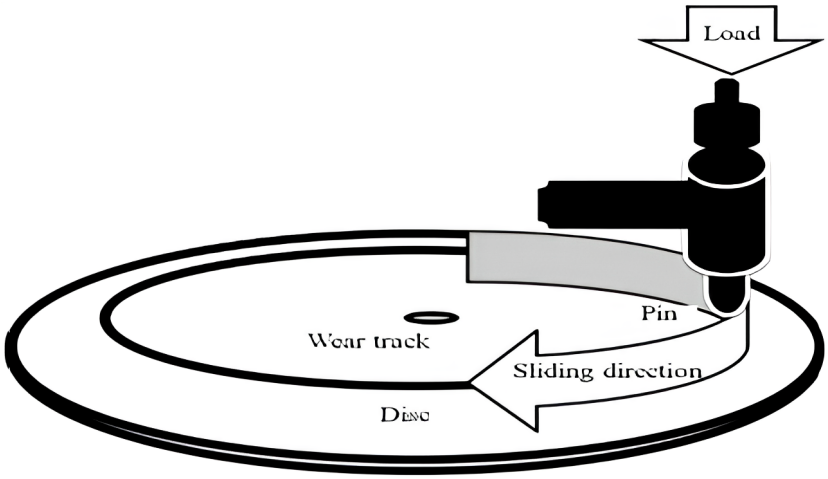

Figure 4: Pin-on-disc set-up.

A study by Manikandan et al. in 2015 focused on AA 6061-MgO composites. These were reinforced with MgO particulates ranging from 1.0 to 2.5 wt.% using the Powder Metallurgy (P/M) technique. The maximum microhardness value of 161.6 VH was achieved with the AA 6061-2%wt.MgO composite. Wear tests conducted under a load of 30 N, at a velocity of 1 m/s and sliding distances ranging from 200–2000 m, showed that 2%wt. MgO led to a wear loss decrease to 0.1292g, indicating enhanced wear resistance [64]. Wear mechanisms in MgO-reinforced composites can be broadly categorized into adhesive, abrasive, and erosive wear. Each of these mechanisms has distinct characteristics and implications for the wear behavior of the composites.

Table 2: Mechanical and Wear Resistance Properties of Various MgO Reinforced Composites

Aluminum Alloys	Reinforcement (MgO) and Method	Mechanical Properties	Wear Resistance Properties (ASTM G-99 standard)	Reference
AA430	SiC+MgO (2.5%, 5%, 7.5 wt.%) Method: Stir casting	Vickers microhardness: 49–61 HV, UTS: 133.21–153.65 MPa	Specific wear rate less than base alloy	[65]
AA 7075	MgO (3, 6, 9 wt.%) Method: Stir casting	Significant increase of hardness	Dry sliding wear: Unreinforced alloys have more wear	[66]
AA 7068	MgO (0, 1, 2, 5%) Method: P/M	Vickers microhardness: 33–68 HV	Enhanced wear resistance	[67]
Pure aluminum	MgO (10, 20, 30, 40vol.%) Method: Vacuum infiltration	Highest microhardness: 71HB, Highest tensile strength: 139 MPa	Lowest wear volume for Al-20%MgO	[68]
Pure aluminum	TiO2+MgO (3, 6, 9, 12 wt.%) Method: P/M	Brinell microhardness: 153–164 HV	Decreasing wear rate for Al/nano-MgO	[69]

Continued on next page

Table 2 – continued from previous page

Aluminum Alloys	Reinforcement (MgO) and Method	Mechanical Properties	Wear Resistance Properties (ASTM G-99 standard)	Reference
A356.1	MgO (0.5, 1, 1.5, 2 wt.%) Method: Stir casting	Brinell microhardness: 98.41 BH	Improved wear resistance	[70]
Pure aluminium	MgO (5, 10, 15 vol.%) Method: P/M	Brinell microhardness: 50.2–56.4 HB	5%MgO reinforced Al-specimens are worn the less	[71]
A 336.0	MgO+RHA Method: Stir casting	Increased hardness with MgO	Minimum wear rate for Al- alloy-10%RHA	[72]
AA 2024	MgO+Al2O3+Gr Method: P/M	Brinell microhardness: 85–111.2 HB	Highest wear resistance for AA 2024/10% Al2O3/ 3%MgO/1.5%Gr	[73]
AZ91 alloy	MgO+Al2O3 Method: In-situ	HV: 64%, YS: 43%, strain hardening: 115%	Highest wear resistance for AZ91-6.5%-composite	[74]
Pure aluminum	MgO (0, 1.5, 2.5, 3.5, 4.5 wt.%) Method: P/M	HV: 16.3%, CS: 13.5%	Optimum properties for Al–5wt.%/Gr–2.5wt.% nano–MgO	[75]
(Sn–Sb–Cu)	MgO+ Al2O3+ FeCr2O4 Method: P/M	–	Mass wear loss affected by FeCr2O4	[76]
ZK60	MgO (0.5% vol.) Method: P/M	Yield Strength: 386–426 MPa, Tensile strength: 419–456 MPa, Elongation: 8.5–9.5%	–	[77]

4.1 Adhesive Wear

Adhesive wear occurs when two contacting surfaces experience molecular attraction and bonding, leading to material transfer from one surface to another. In the context of pin-on-disc tests, adhesive wear can result in material transfer from the pin (the composite) to the disc (a counterpart material). The presence of MgO particles in the composite can act as barriers that reduce the tendency for adhesive wear. These particles enhance the load-bearing capability of the composite and minimize material transfer between the pin and the disc. Consequently, MgO-reinforced composites exhibit improved resistance against adhesive wear.

4.2 Abrasive Wear

Abrasive wear involves the removal of material from a surface due to the presence of hard particles or abrasive agents between the contacting surfaces. This type of wear is particularly relevant in pin-on-disc test setups, especially when the pin or disc undergoes repeated sliding contact with abrasive contaminants. Factors such as particle size, hardness, and concentration significantly affect the abrasive wear behavior. MgO particles, known for their wear resistance, contribute to the reduction of abrasive wear. The hardness and wear resistance of MgO particles can mitigate the abrasive effects of contaminants, thereby enhancing the composite's overall wear resistance.

4.3 Erosive Wear

Erosive wear is caused by the impact of solid particles or liquids on a surface, resulting in material removal. This type of wear is particularly relevant in specific applications, such as in industrial or environmental conditions where the composite may be exposed to high-velocity particles or corrosive liquids. MgO reinforcement, due to its inherent hardness and wear resistance, can offer a level of protection against erosive wear. Thus, it can be inferred that MgO-reinforced composites exhibit enhanced wear resistance due to the mitigating effects of MgO particles on adhesive, abrasive, and erosive wear mechanisms. The specific wear behavior is influenced by various factors, including the size, hardness, and concentration of MgO particles, as well as the testing conditions and environmental factors.

5 Impact of MgO Reinforcement on Aluminum Matrix Composites

Magnesium Oxide (MgO) is a widely used reinforcement material in Aluminum Matrix Composites (AMCs) due to its affordability, ease of incorporation, and beneficial impact on mechanical and wear resistance properties. The various advantages of using MgO as a reinforcement in AMCs are as follows:

- **Cost-Effectiveness:** MgO is often readily available and relatively low in cost. Its ease of incorporation into alloy production processes minimizes additional processing costs.
- **Mechanical Properties:** The addition of MgO particulates enhances tensile and compressive strength. The strong bond between the MgO particles and the aluminum matrix contributes to increased hardness and stiffness.
- **Wear Resistance:** MgO reinforcement significantly reduces the wear rate of AMCs. Its hardness and abrasion resistance minimize material loss during sliding or contact with abrasive surfaces. Additionally, MgO can lower the friction coefficients.
- **Environmental Resistance:** The presence of MgO offers protection against erosion in harsh environments.
- **Toughness:** MgO enhances the material's toughness and its ability to resist crack propagation.
- **Customizability:** The impact of MgO reinforcement can be tailored by adjusting factors like particle size, volume fraction, and distribution.
- **Comparison with Other Reinforcements:** The choice between MgO, Silicon Carbide (SiC), or Aluminum Oxide (Al_2O_3) depends on the application requirements. MgO offers good thermal stability and moderate wear resistance, SiC is ideal for high-temperature and high-wear applications, and Al_2O_3 is preferred for applications requiring excellent corrosion resistance, electrical insulation, and high hardness.

6 Discussions

The analysis of Aluminum Matrix Composites (AMCs) for various mechanical and tribological tests, as detailed in Table 1 and Table 2, reveals that reinforced-based composites consistently demonstrate superior performance compared to monolithic alloys. Among the studied materials, hybrid composites emerge as the most capable. The investigation into Al-MgO based composites has yielded several significant findings, offering valuable insights into composite fabrication, the role of reinforcement, challenges in traditional methods, and the influence of wetting-agents. A fundamental aspect for successfully fabricating Al-MgO based composites lies in achieving a homogenous dispersion of ceramic particulates within the pure alloy matrix. The uniform distribution of both the size and type of MgO particles is essential for the overall success of the composite fabrication process. Conventional stir casting, particularly when working with melted materials at elevated temperatures, poses difficulties in maintaining proper dispersion. These challenges can impede achieving the desired homogeneity and, consequently, the enhancement of material properties. As an alternative to traditional stir casting, electromagnetic stirring has emerged as a potential solution. This technique offers advantages in terms of achieving well-homogeneous dispersed composite materials, overcoming the limitations of conventional methods. Wetting-agents play a crucial role in facilitating strong interfacial bonding between the ceramic particulates and the aluminum matrix. By reducing the sacrificial held angle between the elements, wetting-agents promote effective strengthening within the composite. The presence of porosity within the composite and the level of wettability between the particulates and the pure aluminum alloy are pivotal considerations in the manufacturing process. Addressing these concerns can significantly impact the final material properties. Proper reinforcement achieved through homogeneous dispersion and effective wetting-agents results in a comprehensive enhancement of material properties, including mechanical strength and wear resistance. The findings highlight the potential application of Al-MgO based composites in industries seeking reliable and high-performance materials. Additionally, the scalability of electromagnetic stirring presents an intriguing avenue for industrial production. The findings suggest avenues for further research, such as optimizing the electromagnetic stirring technique, understanding the effects of different wetting-agents, and addressing challenges related to porosity and wettability.

6.1 Applications of AMCs:

In the current landscape, AMCs reinforced with MgO particles find utility in a wide array of applications. For instance, they are instrumental in the automotive sector, particularly in the development of brake components such as discs and pads, offering enhanced braking performance, reduced wear, and superior heat dissipation. Beyond the automotive industry, these composites are invaluable in aerospace for structural components, owing to their high strength-to-weight ratio and thermal stability. They are also suitable for high-temperature applications like jet engines and industrial furnaces. Their corrosion resistance makes them ideal for protective coatings in various industrial settings.

In the biomedical field, the biocompatibility and mechanical strength of Al-MgO composites are being explored for potential use in implants like hip and knee replacements. Additionally, their wear resistance is beneficial for bearings in heavy machinery, reducing maintenance and replacement costs. The lightweight and high-strength properties are advantageous in the production of high-performance sporting goods such as golf clubs and tennis rackets. In the construction sector, these composites serve as robust yet lightweight structural reinforcements. Overall, the versatility of Al-MgO based composites allows them to meet specific challenges across diverse industries, thereby contributing to technological advancements, sustainability, and performance optimization.

6.2 Future research scope for AMCs:

The development of Al-MgO based composites is an area ripe for further research, albeit with its own set of challenges and limitations such as poor wettability, particle agglomeration, and issues related to the reinforcement-matrix interface and processing. Addressing these research gaps necessitates innovative approaches. Computational modeling and simulations could be employed to predict the behavior of these composites under various conditions, thereby optimizing material and processing parameters and reducing the need for extensive experimental work. Another avenue worth exploring is the use of hybrid reinforcements, where MgO particles could be combined with other materials like carbon nanotubes or graphene to achieve synergistic improvements in composite properties. In-situ fabrication methods, where MgO particles are generated within the aluminum matrix during processing, could also be considered to improve particle distribution and bonding. Tailored processing techniques such as spark plasma sintering (SPS) or laser-assisted methods may offer more precise control over fabrication parameters. Additive manufacturing techniques like 3D printing could be leveraged for more intricate designs and controlled deposition of reinforcement materials. Advanced process automation and control systems could also be implemented to ensure consistency and quality in large-scale production. The future of Al-MgO composites is promising, with potential applications spanning diverse sectors. Key areas for future research include advanced fabrication techniques, the development of multi-functional materials, biomedical applications, and energy-efficient transportation solutions. These avenues not only offer the potential for technological advancements but also open up new possibilities for sustainability and performance optimization across various industries.

7 Conclusion:

The extensive literature review conducted in this study has elucidated several key aspects concerning the impact of reinforcement materials on the mechanical and tribological properties of Aluminum Matrix Composites (AMCs). Firstly, AMCs can be effectively fabricated using both powder metallurgy and stir casting techniques. The stir casting method, in particular, offers advantages in terms of cost-effectiveness and suitability for mass production. Secondly, the mechanical and wear-resistant properties of these composites are significantly enhanced with the incorporation of magnesium oxide particles. This suggests that composites with binary reinforcement could serve as better alternatives to those with single reinforcement. Thirdly, the study establishes a positive correlation between microhardness and wear resistance, indicating that AMCs with higher hardness values are likely to demonstrate reduced wear rates and superior performance under abrasive and erosive conditions. Fourthly, the potential applications of AMCs are vast, extending to sectors such as aerospace and marine industries where enhanced mechanical and wear-resistant properties are crucial. Lastly, the use of magnesium oxide as a reinforcing agent in AMCs holds considerable promise for construction materials, enhancing their structural integrity, durability, and overall performance. These reinforced composites meet the current demands in the construction and automotive sectors, including applications in engine components, brake parts, and suspension systems, and are well-positioned to address future challenges.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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Author Contribution

Hartaj Singh: Conceptualization and Writing–original draft; **Kapil Singh**: Data creation; **Sachit Vardhan** Validation and Visualization; **Sanjay Mohan Sharma** Supervision and Writing-reviewing and editing.

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