Science and Applied Journal (SIAP)
Vol 1 (1) 2024 : 60-68

Innovations in Tribology and Surface Engineering: A Systematic Literature Review in Mechanical Engineering

Inovasi dalam Tribologi dan Rekayasa Permukaan: Tinjauan Literatur Sistematis di bidang Teknik Mesin

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ABSTRACT
This study presents a systematic literature review of innovations in the field of tribology and surface engineering, with a focus on the development of superhydrophobic coatings in mechanical engineering. The study background includes an understanding of the importance of tribology and surface engineering in improving material performance, while the research objective is to evaluate recent advances in the application of nanotechnology in the development of superhydrophobic coatings. The research method involves collecting articles from reputable international databases, with the use of relevant keywords to search for relevant articles. The results of the discussion include an understanding of the basic concepts of tribology, the application of nanotechnology in surface engineering, the characteristics of super hydrophobic coatings, and the application of nanotechnology in the development of superhydrophobic coatings. The implication of this research is that a deep understanding of tribology, surface engineering, and nanotechnology can help in developing more efficient and sustainable engineering solutions. This study makes an important contribution to the understanding of the potential of nanotechnology in improving the tribological performance of materials and developing more efficient and sustainable mechanical engineering solutions.
Keywords: tribology, surface engineering, nanotechnology, superhydrophobic coatings, systematic literature review.

ABSTRAK
Studi ini menyajikan sebuah tinjauan literatur sistematis mengenai inovasi dalam bidang tribologi dan rekayasa permukaan, dengan fokus pada pengembangan pelapis superhidrofobik dalam rekayasa mekanika. Latar belakang studi mencakup pemahaman tentang pentingnya tribologi dan rekayasa permukaan dalam meningkatkan kinerja material, sementara tujuan penelitian adalah untuk mengevaluasi kemajuan terbaru dalam penerapan nanoteknologi dalam pengembangan pelapis superhidrofobik. Metode penelitian melibatkan pengumpulan artikel dari database internasional bereputasi, dengan penggunaan kata kunci yang relevan untuk mencari artikel yang relevan. Hasil pembahasan mencakup pemahaman tentang konsep dasar tribologi, aplikasi nanoteknologi dalam rekayasa permukaan, karakteristik lapisan super hidrofobik, dan penerapan nanoteknologi dalam pengembangan pelapis superhidrofobik. Implikasi dari penelitian ini adalah bahwa pemahaman mendalam tentang tribologi, rekayasa permukaan, dan nanoteknologi dapat membantu dalam mengembangkan solusi teknik yang lebih efisien dan berkelanjutan. Studi ini memberikan sumbangan penting dalam pemahaman tentang potensi nanoteknologi dalam meningkatkan kinerja tribology material dan mengembangkan solusi rekayasa mekanika yang lebih efisien dan berkelanjutan.
Kata Kunci: tribologi, rekayasa permukaan, nanoteknologi, pelapis superhidrofobik, systematic literature review.

1. Introduction

Innovations in tribology and surface engineering have gained significant attention in recent years due to their potential impact on various fields such as materials science, mechanical engineering, and medicine. Tribology, the science of friction, lubrication, and wear associated with surfaces in relative motion, has seen advancements in areas such as surface texturing, bioinspired materials, and sustainable tribology (Jonsen, 2021). These advancements have led to a comprehensive understanding of recent advances in tribology, including lubrication, wear, surface engineering, biotribology, high-temperature tribology, and computational tribology (Meng et al., 2022). Moreover, the use of advanced approaches for surface engineering, such as surface texturing and solid lubricants, has shown synergetic effects in tailoring friction and wear (Rosenkranz et al., 2021). Additionally, the development of procedures for characterizing the worn surface of engineering materials in tribological tests has contributed to the understanding of the wear behavior of biomaterial alloys (Almeida et al., 2023).

Furthermore, the application of tribology concepts has extended to diverse fields such as dental composites, bioinspired surfaces, and cartilage research, where tribological properties are essential for understanding friction and lubrication characteristics during joint articulation (Rosa et al., 2022; Шарма & Grewal, 2023; Link et al., 2020; Nordberg et al., 2021). The influence of engineering tribology on society has also been highlighted, emphasizing the potential for value-added developments and the design of lubricants, materials, and fluids towards sustainability (Katiyar et al., 2022). Moreover, the use of mass-produced Cu nanoparticles as lubricant additives has shown remarkable tribological properties, contributing to the reduction of friction and wear (Zhang et al., 2022). Additionally, the development of metal matrix nanocomposites for tribological applications has been systematically summarized, focusing on manufacturing, performance, and mechanisms (Pan et al., 2022).

In conclusion, the recent advancements in tribology and surface engineering have led to a multidisciplinary approach, encompassing materials science, mechanical engineering, medicine, and sustainability. These innovations have not only contributed to a deeper understanding of friction, lubrication, and wear but have also paved the way for the development of novel solutions to persistent problems in various fields.

To comprehensively understand recent innovations in the application of nanotechnology in the development of superhydrophobic coatings in the context of tribology and surface engineering, it is essential to review the latest research in this field. The development of superhydrophobic coatings has shown promise in reducing friction, wear, and corrosion on metal surfaces, thereby enhancing the performance and service life of machine components (Tang, 2024). These coatings have the potential to address the challenges of friction, material wear, and corrosion, which are significant issues in tribology and surface engineering (Kong et al., 2022). The use of nanotechnology in the development of superhydrophobic coatings has garnered attention due to its potential to reduce friction and corrosion, offering a promising solution to these challenges (Nguyen-Tri et al., 2019).

Recent studies have highlighted the potential of nanomaterial technology in developing superhydrophobic coatings with properties that can reduce friction and corrosion on metal surfaces (Uniyal, 2024). The use of nanotechnology in surface engineering has shown promise in enhancing the tribological properties of materials, offering avenues for improving the efficiency and service life of machine components (Zhang et al., 2021). Furthermore, the application of nanotechnology in the development of superhydrophobic coatings has been linked to reducing friction and material wear, addressing critical challenges in tribology and surface engineering (Chan et al., 2021).

The potential of nanotechnology in combating challenges related to friction and corrosion has been recognized in various fields, including maritime applications, where superhydrophobic materials have shown promise (Tang, 2024). Additionally, the influence of microscopic features, such as surface roughness and particle size, on lubrication mechanisms has been studied, highlighting the importance of nanoscale properties in tribology (Kong et al., 2022). Moreover, the use of carbon nanotubes to enhance the tribological characteristics of lubricating engine oil has demonstrated the potential of nanotechnology in improving tribological properties (Kumar & Goyal, 2022).

In conclusion, recent research has emphasized the significant role of nanotechnology in developing superhydrophobic coatings to address challenges related to friction, wear, and corrosion in tribology and surface engineering. The potential of nanomaterial technology in enhancing the tribological properties of materials and reducing friction and corrosion has been a subject of extensive study, offering promising avenues for improving the efficiency and service life of machine components.

Despite much research on superhydrophobic coatings, there is a gap in the literature that systematically details the application of nanotechnology in the development of superhydrophobic coatings. Previous literature reviews tend to be descriptive or focus on certain aspects only, so they do not provide a comprehensive picture of the latest innovations in this field.

The aim of this study was to conduct a comprehensive systematic literature review on the application of nanotechnology in the development of superhydrophobic coatings in the context of tribology and surface engineering. Thus, this research aims to identify the latest trends, technologies and applications in the development of superhydrophobic coatings and evaluate the contribution of nanotechnology to the reduction of friction and corrosion on metal surfaces.

The research question to be answered in this literature review is: "How does the application of nanotechnology influence the development of superhydrophobic coatings to reduce friction and corrosion on metal surfaces in the context of tribology and surface engineering?"

The novelty of this research lies in the systematic approach used to identify the latest innovations in the application of nanotechnology in the development of superhydrophobic coatings. Thus, this research is expected to provide an in-depth understanding of the contribution of nanotechnology to reducing friction and corrosion on metal surfaces.

Research Contribution

The main contribution of this study is to provide a comprehensive literature review on recent innovations in the application of nanotechnology in the development of superhydrophobic coatings. It is hoped that the results of this research can become an important reference for researchers and practitioners in the field of tribology and surface engineering to develop more effective and efficient surface coating technology.

2. Research Methods

This research is based on collecting relevant scientific articles from reputable international databases, with a focus on the use of the Scopus database. The use of Scopus was chosen because this platform provides access to various leading scientific journals in various fields of science, including tribology, surface engineering, and nanotechnology.

Article searches were carried out using a series of keywords relevant to the research topic. Keywords used include terms such as “nanotechnology,” “super hydrophobic coatings,” “tribology,” “surface engineering,” and other variations. Proper use of keywords is key in ensuring relevance and optimal coverage of the articles found.

After conducting a search using specified keywords, relevant articles were selected based on predetermined inclusion and exclusion criteria. The number of articles obtained from this search will be recorded and analyzed as part of the literature evaluation process.

In determining the inclusion and exclusion of articles, certain criteria were used to ensure that only relevant and high-quality articles were included in this literature review. Selected articles will be included in the research based on criteria such as relevance to the research topic, methodological adequacy, and quality of the research conducted.

This research will follow the PRISMA Method (Preferred Reporting Items for Systematic

Reviews and Meta-Analyses) guidelines in carrying out the literature review. This method is a widely accepted framework for reporting systematic literature reviews and meta-analyses. By following PRISMA guidelines, it is hoped that this research can provide a systematic and transparent report on the process and results of the literature review carried out.

These are the details regarding the research methods that will be used in this systematic literature review. The use of the Scopus database, the use of appropriate keywords, the article inclusion and exclusion process, and the application of the PRISMA method are expected to provide a strong and reliable methodological basis for conducting a systematic and comprehensive literature review.

3. Results and Discussions

3.1. Tribology and Surface Engineering: Basic Concepts

Tribology, the study of friction, lubrication, and wear of interacting surfaces in relative motion, is a critical discipline in materials science and engineering (Rosa et al., 2022). Recent research has focused on various aspects of tribology, including advances in the field, such as the application of tribology concepts in specific fields like dental composites (Rosa et al., 2022), the importance of surface roughness in determining tribological properties (Rouf et al., 2021), and the use of advanced approaches for surface engineering to improve tribological properties (Rosenkranz et al., 2021). Additionally, there has been a growing interest in green tribology for sustainable engineering, which includes using natural materials, reducing energy consumption, and minimizing pollution and emissions (Kalin et al., 2019). Furthermore, digital tribology has emerged as a promising method for quantitatively inspecting wear in materials engineering (Almeida et al., 2023).

Surface engineering has also been a key focus, with studies exploring the use of surface texturing to improve tribological performance in various applications, such as mechanical components in automobiles and the friction interface in cylinder liner-piston ring systems (Rosenkranz et al., 2019; Lü, 2023). The development of new surface engineering procedures, such as in situ tribo-fluorination for oil-less hermetic compressor applications, has shown promise in enhancing the performance of soft substrates (Borges et al., 2021). Moreover, the use of diamond-like carbon coatings on mechanical parts has been found to positively influence the operation of hydraulic motors in water, highlighting the potential of surface engineering in overcoming operational limitations (Strmčnik et al., 2019). In conclusion, recent research in tribology and surface engineering has demonstrated significant progress in understanding and improving the tribological properties of materials. These advancements have the potential to contribute to the development of more efficient and sustainable engineering solutions.

Tribology, as a crucial branch of engineering science, delves into the interactions between moving material surfaces, encompassing friction, wear, and lubrication (Li et al., 2019). The study of tribology is essential in engineering applications, particularly in industrial machines and equipment, as it significantly impacts their performance and service life (Lisiecki, 2019). Factors influencing friction and wear include material properties, operational conditions, environment, and surface geometry (Zheng et al., 2023). Material properties such as hardness, strength, and elasticity play a pivotal role in the response to friction and wear forces (Zheng et al., 2023). Operational conditions, including load, speed, and temperature, are also critical in determining friction and wear levels (Zheng et al., 2023).

Surface engineering, aimed at enhancing performance and service life, focuses on reducing friction and corrosion, which can lead to wear and damage (Lisiecki, 2019). Various surface engineering techniques, such as coating, chemical coating, and heat treatment, have been developed to achieve this goal (Lisiecki, 2019). Additionally, the study of carbon matrix composites has shown promising results in improving wear resistance and frictional properties, making them suitable for applications requiring excellent stability and low friction coefficients

(Chen et al., 2022). Furthermore, the effect of wear-induced surface deformation on the stick–slip friction of galvanized automotive steels has been investigated, revealing the intrinsic role of surface topography parameters in stick–slip friction with wear (Gao et al., 2022).

Understanding the basic concepts of tribology and surface engineering is crucial for evaluating the latest innovations in the development of superhydrophobic coatings. By comprehending the interactions between material surfaces and the influencing factors, researchers can identify effective approaches to developing superhydrophobic coatings that reduce friction and corrosion on metal surfaces. This knowledge is essential for advancing the field of surface engineering and developing novel solutions to persistent engineering problems.

3.2. Nanotechnology in Surface Engineering

3.2.1. Introduction to Nanotechnology

Nanotechnology is a rapidly developing field of science that studies materials and devices with nano dimensions, namely at the atomic and molecular scales. In the context of surface engineering, nanotechnology has brought significant innovation by enabling manipulation of the structure and properties of materials at the nanometer level. By exploiting the unique characteristics of nanomaterials, such as high surface area and superior mechanical properties, nanotechnology offers great potential in the development of advanced surface coatings.

3.2.2. Applications of Nanotechnology in the Development of Surface Coatings

The application of nanotechnology in the development of surface coatings has resulted in various innovative technologies. One prominent application example is the use of nanomaterials, such as nanoparticles and nanotubes, as raw materials in the manufacture of superhydrophobic coatings. By using appropriate deposition techniques, these nanomaterials can be directionally arranged to form surface structures with superhydrophobic characteristics, which offer superior protection against friction and corrosion.

3.2.3. Advantages and Challenges of Using Nanotechnology in Tribology

The use of nanotechnology in tribology offers several significant advantages. Nanomaterials have a large surface area, which allows more intensive interactions between material surfaces, thereby increasing lubrication capabilities and reducing friction. In addition, nanomaterials can also provide superior mechanical properties, such as high hardness and wear resistance, which improve the tribological performance of the material.

However, the use of nanotechnology in tribology also faces a number of challenges. One of the main challenges is the problem of stability and dispersion of nanomaterials in the coating matrix. In addition, high production costs and the risk of toxicity of nanomaterials are also obstacles to the commercial application of nanotechnology in tribology.

Thus, a deep understanding of nanotechnology in surface engineering is important for identifying the potential and limitations in the development of innovative surface coatings. Through the integration of nanotechnology in the field of tribology, it is hoped that surface coatings can be created that are more effective and efficient in reducing friction and corrosion on metal surfaces.

3.3. Superhydrophobic Coatings: Concept and Characteristics

3.3.1. Superhydrophobic Coatings

Superhydrophobic coatings are a type of surface coating that has the ability to repel water to the extreme. This superhydrophobic property is determined by a surface structure that has minimal contact with water droplets, so that the water droplets can roll or detach easily from the surface. In the context of tribology and surface engineering, superhydrophobic coatings aim to reduce friction and corrosion on metal surfaces by repelling water and preventing contact between water and the metal surface.

3.3.2. Methods for Development of Superhydrophobic Coatings

The development of superhydrophobic coatings involves the use of a variety of techniques and methods. One commonly used approach is to modify the surface structure using physical or chemical techniques. An example is the use of micronanotechnology techniques to produce surface structures with superhydrophobic characteristics, such as using lasers or chemical etching. In addition, layer deposition methods are also often used, including chemical vapor deposition (CVD) or physical vapor deposition (PVD), to produce coatings that have superhydrophobic properties.

3.3.3. Characteristics and Performance of Superhydrophobic Coatings

Superhydrophobic coatings have a number of characteristics that are important for their performance and application. One of them is a high water contact angle, namely the angle between the coating surface and water droplets that reaches or exceeds 150 degrees. In addition, low light scattering and self-cleaning ability are also desirable characteristics in superhydrophobic coatings. The performance of superhydrophobic coatings in reducing friction and corrosion also depends greatly on factors such as surface structure, raw materials used, and operational environmental conditions.

By understanding the concept and characteristics of superhydrophobic coatings, we can identify the latest technologies and innovations in the development of surface coatings that are effective in reducing friction and corrosion on metal surfaces. Through this research, it is hoped that a deeper understanding will be found about the potential and challenges in developing superhydrophobic coatings, as well as the contribution of nanotechnology in improving the performance of these coatings.

3.4. Application of Nanotechnology in the Development of Superhydrophobic Coatings

Superhydrophobic coatings have gained significant attention due to their wide range of applications, including self-cleaning, anti-icing, and oil/water separation (Wang et al., 2019). The development of these coatings has been greatly influenced by nanotechnology, which has enabled the creation of surfaces with enhanced properties (Parvate et al., 2020). Nanotechnology has been instrumental in the design of bioinspired superhydrophobic surfaces, incorporating double-scale structures and water-repellent compounds (Nguyen-Tri et al., 2019). Furthermore, the use of nanotechnology in creating superhydrophobic concrete has led to enhanced anticorrosive and deicing resistance (Kravanja et al., 2021). Additionally, the multifunctional applications of superhydrophobic coatings, such as photothermal therapy, have been made possible through the integration of nanotechnology (Wang et al., 2022). The durability and versatility of superhydrophobic coatings have also been explored, highlighting the potential for printed patterning and internal tubular coating using nanotechnology (Kwak et al., 2021). Moreover, the application of superhydrophobic coatings in healthcare has been a subject of interest, with nanotechnology playing a crucial role in advancing healthcare-related materials (Biswas & Gupta, 2021). In conclusion, the application of nanotechnology in the development of superhydrophobic coatings has significantly expanded the capabilities and potential applications of these coatings, ranging from healthcare to infrastructure and environmental protection.

4. Conclusion

This study outlines results and discussions related to innovations in tribology and surface engineering, as well as the application of nanotechnology in the development of superhydrophobic coatings in mechanical engineering. Through a systematic literature review, we can conclude that there has been significant progress in the understanding and development of the tribological properties of materials, especially in reducing friction and corrosion on metal surfaces. Tribology and surface engineering play an important role in improving material performance, and recent research has identified a variety of innovative approaches, including the use of digital technologies and green tribology strategies, to achieve this goal.

The application of nanotechnology in the development of superhydrophobic coatings has shown promising results in producing coatings with superior superhydrophobic properties. Through a nanotechnology approach, researchers can design surface structures with superhydrophobic characteristics, which offer effective protection against friction and corrosion on metal surfaces. Nevertheless, challenges such as stability and dispersion of nanomaterials still need to be overcome to realize the commercial application of nanotechnology in tribology.

The implication of this research is that a deep understanding of tribology, surface engineering, and nanotechnology can help in developing more efficient and sustainable engineering solutions. However, this study has limitations, such as limitations in access to certain articles and the possibility of bias in article selection. Therefore, future research could focus on broadening the scope of literature considered and addressing such potential biases.

For future research, it is recommended to conduct further research to explore the integration of nanotechnology in the development of superhydrophobic coatings for specific applications, such as in the automotive, aviation or healthcare industries. In addition, further research can also investigate the use of nanotechnology in improving the stability and dispersion of nanomaterials in coating matrices, as well as reducing production costs and the risk of toxicity. Thus, future research is expected to increase our understanding of the potential of nanotechnology in improving the tribological performance of materials and developing more efficient and sustainable mechanical engineering solutions.

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