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ҚАЙЫРЫМДЫЛЫҚ ҚОРЫ
HALYK
CHARITY FOUNDATION

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
«ХАЛЫҚ» ЖҚ

БАЯНДАМАЛАРЫ

ДОКЛАДЫ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ КАЗАХСТАН»
ЧФ «ХАЛЫҚ»

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ҚАЙЫРЫМДЫЛЫҚ ҚОРЫ
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ЧФ «ХАЛЫҚ»

В 2016 году для развития и улучшения качества жизни казахстанцев был создан частный Благотворительный фонд «Халык». За годы своей деятельности на реализацию благотворительных проектов в областях образования и науки, социальной защиты, культуры, здравоохранения и спорта, Фонд выделил более 45 миллиардов тенге.

Особое внимание Благотворительный фонд «Халык» уделяет образовательным программам, считая это направление одним из ключевых в своей деятельности. Оказывая поддержку отечественному образованию, Фонд вносит свой посильный вклад в развитие качественного образования в Казахстане. Тем самым способствуя росту числа людей, способных менять жизнь в стране к лучшему – профессионалов в различных сферах, потенциальных лидеров и «великих умов». Одной из значимых инициатив фонда «Халык» в образовательной сфере стал проект Ozgeris powered by Halyk Fund – первый в стране бизнес-инкубатор для учащихся 9-11 классов, который помогает развивать необходимые в современном мире предпринимательские навыки. Так, на содействие малому бизнесу школьников было выделено более 200 грантов. Для поддержки талантливых и мотивированных детей Фонд неоднократно выделял гранты на обучение в Международной школе «Мирас» и в Astana IT University, а также помог казахстанским школьникам принять участие в престижном конкурсе «USTEM Robotics» в США. Авторские работы в рамках проекта «Тәлімгер», которому Фонд оказал поддержку, легли в основу учебной программы, учебников и учебно-методических книг по предмету «Основы предпринимательства и бизнеса», преподаваемого в 10-11 классах казахстанских школ и колледжей.

Помимо помощи школьникам, учащимся колледжей и студентам Фонд считает важным внести свой вклад в повышение квалификации педагогов, совершенствование их знаний и навыков, поскольку именно они являются проводниками знаний будущих поколений казахстанцев. При поддержке Фонда «Халык» в южной столице был организован ежегодный городской конкурс педагогов «Almaty Digital Ustaz.

Важной инициативой стал реализуемый проект по обучению основам финансовой грамотности преподавателей из восьми областей Казахстана, что должно оказать существенное влияние на воспитание финансовой грамотности и предпринимательского мышления у нового поколения граждан страны.

Необходимую помощь Фонд «Халык» оказывает и тем, кто особенно остро в ней нуждается. В рамках социальной защиты населения активно проводится работа по поддержке детей, оставшихся без родителей, детей и взрослых из социально уязвимых слоев населения, людей с ограниченными возможностями, а также обеспечению нуждающихся социальным жильем, строительству социально важных объектов, таких как детские сады, детские площадки и физкультурно-оздоровительные комплексы.

В копилку добрых дел Фонда «Халык» можно добавить оказание помощи детскому спорту, куда относится поддержка в развитии детского футбола и карате в нашей стране. Жизненно важную помощь Благотворительный фонд «Халык» оказал нашим соотечественникам во время недавней пандемии COVID-19. Тогда, в разгар тяжелой борьбы с коронавирусной инфекцией Фонд выделил свыше 11 миллиардов тенге на приобретение необходимого медицинского оборудования и дорогостоящих медицинских препаратов, автомобилей скорой медицинской помощи и средств защиты, адресную материальную помощь социально уязвимым слоям населения и денежные выплаты медицинским работникам.

В 2023 году наряду с другими проектами, нацеленными на повышение благосостояния казахстанских граждан Фонд решил уделить особое внимание науке, поскольку она является частью общественной культуры, а уровень ее развития определяет уровень развития государства.

Поддержка Фондом выпуска журналов Национальной Академии наук Республики Казахстан, которые входят в международные фонды Scopus и Wos и в которых публикуются статьи отечественных ученых, докторантов и магистрантов, а также научных сотрудников высших учебных заведений и научно-исследовательских институтов нашей страны является не менее значимым вкладом Фонда в развитие казахстанского общества.

С уважением,
Благотворительный Фонд «Халык»!

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫНЫҢ
БАЯНДАМАЛАРЫ **2023 • 4**

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РЕДАКЦИЯЛЫҚ АЛҚА:

РАМАЗАНОВ Тілекқабыл Сәбитұлы, (бас редактордың орынбасары), физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі (Алматы, Қазақстан), H = 26

РАМАНҚҰЛОВ Ерлан Мирхайдарұлы, (бас редактордың орынбасары), профессор, ҚР ҰҒА корреспондент-мүшесі, Ph.D биохимия және молекулалық генетика саласы бойынша Ұлттық биотехнология орталығының бас директоры (Нұр-Сұлтан, Қазақстан), H = 23

САНГ-СУ Квак, PhD (биохимия, агрохимия), профессор, Корей биоғылым және биотехнология ғылыми-зерттеу институты (KRIBB), өсімдіктердің инженерлік жүйелері ғылыми-зерттеу орталығының бас ғылыми қызметкері, (Дэчон, Корея), H = 34

БЕРСІМБАЕВ Рахметқажы Ескендірұлы, биология ғылымдарының докторы, профессор, ҚР ҰҒА академигі, Еуразия ұлттық университеті. Л.Н. Гумилев (Нұр-Сұлтан, Қазақстан), H = 12

ӘБИЕВ Руфат, техника ғылымдарының докторы (биохимия), профессор, Санкт-Петербург мемлекеттік технологиялық институты «Химиялық және биотехнологиялық аппаратураны оңтайландыру» кафедрасының меңгерушісі, (Санкт-Петербург, Ресей), H = 14

ЛОКШИН Вячеслав Нотанович, медицина ғылымдарының докторы, профессор, ҚР ҰҒА академигі, «PERSONA» халықаралық клиникалық репродуктология орталығының директоры (Алматы, Қазақстан), H = 8

СЕМЕНОВ Владимир Григорьевич, биология ғылымдарының докторы, профессор, Чуваш республикасының еңбек сіңірген ғылым қайраткері, «Чуваш мемлекеттік аграрлық университеті» Федералдық мемлекеттік бюджеттік жоғары білім беру мекемесі Акушерлік және терапия кафедрасының меңгерушісі, (Чебоксары, Ресей), H = 23

ФАРУК Асана Дар, Хамдар аль-Маджида Хамдард университетінің шығыс медицина факультеті, Шығыс медицинасы колледжінің профессоры, (Карачи, Пәкістан), H = 21

ЩЕПЕТКИН Игорь Александрович, медицина ғылымдарының докторы, Монтана штаты университетінің профессоры (Монтана, АҚШ), H = 27

КАЛАНДРА Пьетро, PhD (физика), наноқұрылымды материалдарды зерттеу институтының профессоры (Рим, Италия), H = 26

МАЛЬМ Анна, фармацевтика ғылымдарының докторы, профессор, Люблин медицина университетінің фармацевтика факультетінің деканы (Люблин, Польша), H = 22

БАЙМҰҚАНОВ Дастан Асылбекұлы, ауыл шаруашылығы ғылымдарының докторы, ҚР ҰҒА корреспондент мүшесі, "Мал шаруашылығы және ветеринария ғылыми-өндірістік орталығы" ЖШС мал шаруашылығы және ветеринарлық медицина департаментінің бас ғылыми қызметкері (Нұр-Сұлтан, Қазақстан), H=1

ТИГИНЯНУ Ион Михайлович, физика-математика ғылымдарының докторы, академик, Молдова Ғылым Академиясының президенті, Молдова техникалық университеті (Кишинев, Молдова), H = 42

ҚАЛИМОЛДАЕВ Мақсат Нұрәділұлы, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі (Алматы, Қазақстан), H = 7

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QUEVEDO Hemando, профессор, Ядролық ғылымдар институты (Мехико, Мексика), H = 28

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ТАКИБАЕВ Нұрғали Жабағаұлы, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі, әл-Фараби атындағы Қазақ ұлттық университеті (Алматы, Қазақстан), H = 5

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ДАВЛЕТОВ Асқар Ербуланович, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі, әл-Фараби атындағы Қазақ ұлттық университеті (Алматы, Қазақстан), H = 12

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ДОКЛАДЫ **2023 • 4**
НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК РЕСПУБЛИКИ КАЗАХСТАН

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СЕМЕНОВ Владимир Григорьевич, доктор биологических наук, профессор, заслуженный деятель науки Чувашской Республики, заведующий кафедрой морфологии, акушерства и терапии, Федеральное государственное бюджетное образовательное учреждение высшего образования «Чувашский государственный аграрный университет» (Чебоксары, Чувашская Республика, Россия), H = 23

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ЩЕПЕТКИН Игорь Александрович, доктор медицинских наук, профессор Университета штата Монтана (США), H = 27

КАЛАНДРА Пьетро, доктор философии (Ph.D, физика), профессор Института по изучению наноструктурированных материалов (Рим, Италия), H = 26

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БАЙМУКАНОВ Дастанбек Асылбекович, доктор сельскохозяйственных наук, член-корреспондент НАН РК, главный научный сотрудник Департамента животноводства и ветеринарной медицины ТОО «Научно-производственный центр животноводства и ветеринарии» (Нур-Султан, Казахстан), H=1

ТИГИНЯНУ Ион Михайлович, доктор физико-математических наук, академик, президент Академии наук Молдовы, Технический университет Молдовы (Кишинев, Молдова), H = 42

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COMPOSITE COATINGS: A COMPREHENSIVE REVIEW OF MATERIALS, METHODS AND APPLICATIONS

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Abstract. Composite coatings have emerged as a pivotal solution in enhancing material properties, offering synergistic combinations of two or more constituents to achieve superior performance characteristics. This comprehensive review delves into the vast realm of composite coatings, elucidating the diverse materials utilized, the myriad of fabrication methods, and their multifaceted applications across various industries. From the integration of metal-ceramic coatings in aerospace for high-temperature stability to the use of nanocomposite coatings harnessing nanoparticles for enhanced mechanical and functional capabilities, the scope of these coatings is expansive. Moreover, with the onset of green and sustainable fabrication techniques, composite coatings are poised to meet both performance and environmental benchmarks. Through a methodical examination of peer-reviewed publications, this review aims to provide readers with a holistic understanding of composite coatings, highlighting their evolution, current trends, challenges, and the future outlook. It stands as a testament to the transformative potential of composite coatings in reshaping material science and engineering applications.

Keywords: composite coatings, fabrication methods, materials science, nanocomposite coatings, mechanical properties, wear resistance

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КОМПОЗИТТІК ҚАПТАМАЛАР: МАТЕРИАЛДАРДЫ, ӘДІСТЕРДІ ЖӘНЕ ҚОЛДАНБАЛАРДЫ КЕШЕНДІ ШОЛУ

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Аннотация. Композиттік қаптамалар жоғары өнімділікке қол жеткізу үшін екі немесе одан да көп компоненттердің синергетикалық комбинацияларын ұсына отырып, материалдың қасиеттерін жақсартудың негізгі шешімі болды. Бұл жан-жақты шолу композиттік қаптамалардың кең өрісін зерттейді, қолданылатын материалдардың әртүрлілігін, көптеген өндіру әдістерін және олардың көптеген салаларда қолданылуын көрсетеді. Бұл қаптамалардың қолданылу аясы кең: аэроғарыш өнеркәсібіне жоғары температура тұрақтылығын қамтамасыз ету үшін керамикалық-металл жабындарын енгізуден механикалық және функционалдық қасиеттерді жақсарту үшін нанобөлшектерді пайдаланатын нанокомпозиттік қаптамаларды қолдануға дейін. Сонымен қатар, экологиялық таза және тұрақты өндіріс технологияларының пайда болуымен композиттік жабындар өнімділікке де, экологиялық стандарттарға да жауап беруге дайын. Бұл шолудың мақсаты рецензияланған басылымдарды әдістемелік зерттеу болып табылады, оның мақсаты оқырмандарға композиттік жабындар туралы тұтас көзқараспен қамтамасыз ету, олардың эволюциясын, қазіргі тенденцияларын, проблемаларын және болашақ перспективаларын көрсету. Бұл материалтану мен техниканы қолдануды өзгертуде композиттік қаптамалардың трансформациялық әлеуетінің дәлелі.

Түйін сөздер: композиттік қаптамалар, өндіріс әдістері, материалтану, нанокомпозиттік қаптамалар, механикалық қасиеттер, тозуға төзімділік

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КОМПОЗИТНЫЕ ПОКРЫТИЯ: КОМПЛЕКСНЫЙ ОБЗОР МАТЕРИАЛОВ, МЕТОДОВ И ПРИМЕНЕНИЙ

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Аннотация. Композитные покрытия стали ключевым решением в улучшении свойств материалов, предлагая синергетические комбинации двух или более компонентов для достижения превосходных эксплуатационных характеристик. Этот всесторонний обзор углубляется в обширную сферу композитных покрытий, раскрывая разнообразные используемые материалы, множество методов изготовления и их многогранное применение в различных отраслях. Область применения этих покрытий обширна: от внедрения металлокерамических покрытий в аэрокосмическую промышленность для обеспечения высокотемпературной стабильности до использования нанокомпозитных покрытий, использующих наночастицы для улучшения механических и функциональных свойств. Более того, с появлением экологически чистых и устойчивых технологий производства композитные покрытия готовы соответствовать как эксплуатационным, так и экологическим стандартам. Целью данного обзора является методическое изучение рецензируемых публикаций, цель которого – предоставить читателям целостное представление о композитных покрытиях, освещая их эволюцию, текущие тенденции, проблемы и перспективы на будущее. Это является свидетельством преобразующего потенциала композитных покрытий в изменении применения материаловедения и техники.

Ключевые слова: композиционные покрытия, методы изготовления, материаловедение, нанокомпозитные покрытия, механические свойства, износостойкость

Introduction

Composite coatings are typically composed of two or more distinct materials blended strategically to enhance properties beyond what individual components can offer, such as improved wear resistance, corrosion protection, electrical conductivity, and thermal insulation (Ang, 2014). By capitalizing on the synergistic advantages of their combined constituents, composite coatings frequently surpass the performance of traditional single-material counterparts across various applications. Delving into the myriad of composite coatings available, we encounter a vast spectrum tailored to specific uses. Metal-Ceramic coatings merge the ductility of metals with ceramics' hardness and wear resistance, making them suitable for aerospace applications due to their high-temperature resilience. Polymer-Ceramic coatings, which marry polymers' flexibility with the robustness of ceramics, commonly address wear resistance and corrosion protection. In the realm of electronics, Metal-Polymer coatings fuse metals' strength and conductivity with polymers' flexibility and insulation. Nano-composite coatings, integrating nanoparticles within their structure, offer enhanced mechanical attributes, protective barriers, and specialized functions, like the antibacterial capabilities of coatings containing silver nanoparticles. Multi-layered coatings employ a layered approach, with each stratum serving distinct roles, such as a foundational layer for corrosion resistance topped with one for UV shielding (Ashokkumar et al., 2021). Hybrid coatings blend both organic and inorganic constituents to strike a balance between hardness and adaptability, often intertwining polymers with sol-gel processes. Functional Gradient coatings shift their composition from their point of attachment to their external surface, adjusting properties like hardness, thermal conductivity, or electrical conductivity along the gradient. Advanced Self-healing coatings possess the unique ability to revert to their initial condition post-minor damages, usually facilitated by releasing contained healing compounds or triggering specific chemical reactions. The selection of a composite coating is inherently tied to its intended application and the desired characteristics. As materials science propels forward, the evolution of composite coatings continues, branching out to serve an expanding array of specialized needs (Chen et al., 2007).

Historically, the need for composite coatings can be traced back to humanity's quest for materials that could combine the best qualities of two or more constituents to address specific challenges not achievable by a single material. From ancient civilizations, who inadvertently developed composite materials like mud bricks reinforced with straw to prevent cracking, to more deliberate efforts like the early metallurgists alloying copper and tin to make more durable bronze, the groundwork for composite coatings was laid. As we transitioned into the industrial age, the demands of rapidly evolving industries necessitated more sophisticated protective coatings. The 20th century witnessed significant strides in the development of composite coatings. Aerospace and automotive sectors, for example, began to prioritize lightweight yet durable coatings, leading to innovations like polymer-matrix composites (Chen et al., 2020). Concurrently, the electronics sector was leaning towards coatings that could offer protection without compromising conductivity. By the latter half of the century, nanotechnology had entered the fray, allowing for the manipulation of materials on an atomic or molecular scale, birthing nano-composite coatings with unprecedented properties. This continual evolution has been fueled by both the challenges posed by new technological frontiers and our expanding understanding of materials science. Today, composite coatings, born from centuries of innovation and necessity, have become integral to numerous industries, each iteration reflecting humanity's drive to better its surroundings (De Lima-Neto et al., 2007).

The fundamental principle behind composite coatings lies in the synergy of combining two or more materials to achieve properties that individual components might not offer on their own. At its core, the concept revolves around compensating for the deficiencies of one material by incorporating the strengths of another, leading to an enhanced composite performance. For instance, while one material might possess exceptional hardness but is prone to brittleness, another could offer the needed ductility or flexibility but might lack the required wear resistance. By merging these two, the resulting composite coating can achieve both hardness and flexibility, addressing a wider array of needs than either material could on its own. On a microscopic level, the distribution, interaction, and bonding between the combined materials play pivotal roles in defining the characteristics of the composite coating. Interfacial bonding between the constituents, particle size and distribution, and even the orientation of fibers or particles can greatly influence the resultant properties. Furthermore, composite coatings don't just bank on the passive combination of materials; they often leverage the active interactions between them, such as chemical reactions or phase changes, to instigate novel properties or functionalities. In essence, the principle of composite coatings is a strategic alliance of materials, capitalizing on their individual strengths while mitigating their weaknesses, to create a product that transcends the capabilities of its individual components (Deepaka et al., 2019).

Utilizing multiple phases or materials in composite coatings offers a plethora of advantages by marrying the inherent properties of each constituent, enabling the creation of coatings that outpace the performance metrics of individual components. One of the primary benefits is the potential for tailor-made solutions. By judiciously selecting and combining materials, designers can achieve a specific set of desired properties, catering to niche applications or stringent performance criteria. This multi-material approach also allows for enhanced durability. For instance, while one material may provide hardness and wear resistance, another might impart corrosion resistance, ensuring the coating's longevity across multiple fronts. Furthermore, the incorporation of multiple phases can lead to the emergence of new functionalities, often unattainable by single-phase materials. For example, a composite coating combining conductive and insulating materials might exhibit controlled electrical conductivity, making it suitable for specialized electronic applications (Dong et al., 2009). Additionally, these coatings can provide a balanced combination of mechanical, thermal, and chemical properties, thereby optimizing performance. The presence of one material can also mitigate the drawbacks of another, ensuring a holistic improvement. For example, the brittleness of ceramics can be offset by combining them with ductile metals or polymers. On a broader scale, multi-phase systems can be economically advantageous, as cheaper materials can be combined with more expensive ones to produce cost-effective solutions without compromising on quality. In essence, the amalgamation of multiple phases or materials in composite coatings unlocks a vast realm of possibilities, enabling the creation of high-performance, versatile, and efficient coatings tailored for an expansive range of applications (Gonzalez et al., 2016).

Materials and Methods

To prepare this comprehensive review on composite coatings, a meticulous and structured literature search was executed across several established scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar. Preliminary screening eliminated duplicates, reviews, and non-relevant articles based on their titles and abstracts. The remaining articles underwent a detailed assessment, wherein their full text was scrutinized for relevance and quality of content. Inclusion criteria involved articles that presented novel insights, demonstrated unique applications, or expanded on advanced fabrication techniques for composite coatings. Data extracted from these sources were categorized based on material type, fabrication method, and application. Additionally, references cited within these primary sources were reviewed to ensure a comprehensive capture of relevant studies. This methodical approach provided a broad yet in-depth perspective on the evolution, current state, and future prospects of composite coatings in various industries and applications (Gonzalez et al., 2016).

Results and Discussion

Fabrication Techniques. Electro-deposition, a widely used technique in surface engineering, involves depositing a material onto a substrate by applying an electric current through an electrolytic solution containing metal ions. This process not only allows for precise thickness control and uniform coatings but also facilitates the incorporation of various secondary materials into the primary matrix, thereby creating composite coatings (Hasani et al., 2021). The pivotal role of chemical reactions in this process can't be overstated. When a potential is applied across the cathode (the object to be coated) and the anode (often a sacrificial electrode), metal cations from the electrolyte migrate towards the cathode, where they undergo a reduction reaction. This chemical transformation leads to the metal cations gaining electrons and being deposited as a metal onto the cathode's surface. Beyond the basic metal deposition, other in-situ chemical reactions can be leveraged to incorporate secondary materials, such as nanoparticles, fibers, or other agents, into the coating. For example, certain reactive species in the electrolyte can precipitate or co-deposit alongside the primary metal, leading to the formation of composite coatings with enhanced properties. Such in-situ chemical reactions during electro-deposition can significantly influence the morphology, composition, and overall performance of the resultant coatings. For instance, by controlling the bath composition, pH, temperature, and electrical parameters, one can promote the co-deposition of ceramic particles within a metal matrix, creating a metal-ceramic composite coating with augmented hardness and wear resistance. In summary, electro-deposition combined with in-situ chemical reactions offers a versatile tool in materials engineering, enabling the synthesis of advanced composite coatings with tailor-made properties (Huh et al., 2014).

One of the classic examples of obtaining composite coatings through electro-deposition accompanied by chemical reactions is the co-deposition of nickel and dispersed hard particles, such as silicon carbide (SiC) or tungsten carbide (WC), to produce composite coatings with enhanced wear resistance. In the case of a Nickel-Silicon Carbide (Ni-SiC) composite coating, the electrolyte bath is first prepared using a nickel salt solution, such as nickel sulfate, as the source of nickel ions. SiC particles intended for co-deposition are then dispersed in this solution. To maintain the dispersion of SiC particles and prevent them from settling, stabilizing agents and surfactants are often added (Ibrahim et al., 2007). During the electro-deposition process, an electrical potential is applied between the anode, typically made of pure nickel, and the cathode, which is the substrate to be coated. As the current flows, nickel ions migrate from the solution towards the cathode, undergoing a reduction reaction to form solid nickel. Simultaneously, the SiC particles move, driven by the convective currents in the bath and possibly by electrophoretic effects, becoming embedded in the growing nickel matrix. The primary chemical reaction at the cathode involves the reduction of nickel ions, represented as

$$Ni^{2+} + 2e^{-} \rightarrow Ni\ (s) \qquad (1)$$

As the nickel metal deposits onto the cathode, the dispersed SiC particles become entrapped within the metal matrix, leading to the formation of a composite coating. After deposition, the coated substrate can be subjected to heat treatment or other post-processing steps to enhance properties such as hardness, adhesion, or corrosion resistance. The resulting Ni-SiC composite coating offers significant advantages over pure nickel coatings. The embedded SiC particles increase the hardness of the coating, reduce the wear rate, and can enhance the coating's resistance to certain types of corrosion, making Ni-SiC coatings particularly beneficial for applications like mechanical components, tools, and molds where enhanced wear resistance is paramount.

Thermal spraying is a versatile coating process wherein a material, often in the form of powder or wire, is heated to a molten or semi-molten state and then propelled as fine droplets onto a surface, forming a protective coating. This heating is achieved using various heat sources, such as oxy-fuel flames, plasma jets, or electric arcs. The resultant coatings can serve a myriad of purposes, from corrosion and wear resistance to thermal and electrical insulation. For instance, consider the application of a ceramic coating, like zirconia (ZrO□), onto an aerospace component for thermal barrier purposes. In a plasma-sprayed thermal barrier coating process, zirconia powder, often stabilized with yttria (Y□O□), is fed into a plasma jet. Here, the powder is rapidly heated to its melting point. As the molten zirconia particles exit the plasma jet, they are propelled towards the substrate (Ivanov, 2021). Upon impact, these particles flatten, solidify, and adhere to the surface, creating a lamellar structure characteristic of sprayed coatings. The primary chemical reaction, in this case, is not a complex transformative one but rather a phase change

$$\text{Metal (M)} + n/2O_2 \rightarrow \text{Metal Oxide } (M_nO_2)$$
$$\text{Tetragonal } ZrO_2 \rightarrow \text{Cubic } ZrO_2$$
$$\text{Monoclinic } ZrO_2 \rightarrow \text{Tetragonal } ZrO_2$$

The zirconia undergoes a transition from solid (powder form) to liquid (molten state) and then back to a solid upon deposition. However, during this process, potential interactions with ambient gases, especially if not adequately controlled, can lead to oxidation or other minor chemical changes. The finished zirconia-yttria coating acts as a thermal barrier, protecting the underlying component from excessive temperatures, making it especially valuable in high-temperature applications like jet engine turbines.

Layer-by-layer (LbL) assembly is a versatile method for fabricating multi-layered thin films with nanometer precision by sequentially adsorbing oppositely charged materials onto a substrate. This method harnesses the electrostatic interactions between materials of alternate charges, though other forces like hydrogen bonding or hydrophobic interactions can also be exploited. For instance, let's consider the LbL assembly of a polyelectrolyte multilayer using poly (allylamine hydrochloride) (PAH) as the polycation and poly(styrenesulfonate) (PSS) as the polyanion. Starting with a cleaned substrate, the process might involve immersing the substrate into a solution of PAH, allowing the positively charged PAH to adsorb onto the surface. After rinsing to remove any loosely bound material, the substrate is then immersed in a solution of the negatively charged PSS, leading to the adsorption of PSS over the PAH layer due to electrostatic attraction. The chemical reactions involved are essentially ionic attractions between the amine groups of PAH and the sulfonate groups of PSS. This process can be repeated multiple times to create a multilayer film of desired thickness and properties. The LbL assembly offers precise control over film thickness, composition, and function, making it a valuable technique in fields ranging from sensors to drug delivery systems (Laad, 2022).

The layer-by-layer (LbL) assembly of polyelectrolytes, as described in the scenario with poly (allylamine hydrochloride) (PAH) and poly (styrenesulfonate) (PSS), mainly relies on electrostatic interactions between charged groups on the polymer chains. The specific chemical groups involved in this interaction are the amine groups from PAH and the sulfonate groups from PSS.

The amine group in PAH, when protonated (common in aqueous solutions), carries a positive charge:

$NH_2 \rightarrow NH_3^+$

On the other hand, the sulfonate group in PSS is an anion and carries a negative charge:

$SO_3H \rightarrow SO_3^- + H^+$

The electrostatic interaction, which isn't a traditional chemical reaction where bonds are broken and formed but rather a physical interaction based on charge attraction, can be represented as:

$NH_3^+ + SO_3^- \rightarrow NH_3^+SO_3^-$

This interaction represents the ionic pairing between the protonated amine (cationic site) of PAH and the sulfonate anion of PSS. This pairing is the driving force behind the LbL assembly of these particular polyelectrolytes. Repeated immersion and rinsing cycles effectively build up the multilayered structure on the substrate due to these interactions. The beauty of the LbL technique is that it harnesses these relatively simple interactions to construct intricately designed architectures on surfaces.

The sol-gel method is a widely-used technique to produce inorganic and hybrid organic-inorganic materials at a molecular level. It involves the transition of a system from a liquid 'sol' (colloidal solution) into a solid 'gel' phase. The sol-gel process starts with the hydrolysis and condensation of metal alkoxide precursors. For instance, if we consider the synthesis of silica (SiO_2) coatings or films, tetraethyl orthosilicate (TEOS) is a common precursor. When TEOS is introduced to an aqueous solution with an acid or base catalyst, it undergoes hydrolysis to produce silicic acid, which then further undergoes condensation reactions to form a three-dimensional network of SiO_2. The primary reactions involved are (Li et al., 2022) :

1. Hydrolysis:

$Si(OC_2H_5)_4+H_2O \rightarrow Si(OC_2H_5)_3(OH)+C_2H_5OH$

2. Condensation:

$2Si(OC_2H_5)_3(OH) \rightarrow Si(OC_2H_5)_3OSi(OC_2H_5)_3+H_2O$

Subsequent reactions lead to the formation of Si-O-Si bonds, creating a silica network. By controlling the processing conditions, one can obtain diverse materials ranging from thin films to monolithic ceramics through the sol-gel method. This process also allows for the inclusion of dopants or the creation of hybrid materials, thereby broadening the scope of obtainable materials and their potential applications. The resultant gels can be dried and further heat-treated to produce glasses, ceramics, or aerogels, depending on the desired end-product and processing conditions.

Chemical vapor deposition (CVD) is a versatile technique used to produce high-quality, high-performance solid materials, typically in the form of thin films. In CVD, a precursor gas is introduced into a chamber, where it reacts or decomposes on a heated substrate to deposit a solid material. The by-products of this process are typically gaseous and are evacuated from the chamber. One classic example of CVD is the deposition of pure silicon for semiconductor applications. In this process, silane (SiH_4) is used as the precursor gas. When silane is introduced into the CVD chamber and comes into contact with a heated substrate, it decomposes to deposit silicon:

$SiH_4 \rightarrow Si+2H_2$

The hydrogen gas produced in this reaction is then removed from the chamber. The deposition rate, film quality, and other properties can be meticulously controlled by adjusting parameters such as substrate temperature, precursor gas flow rate, and chamber pressure. Apart from elemental deposits like silicon, CVD can be utilized for the deposition of compound materials, such as metal oxides, nitrides, and carbides. The precise control CVD offers over film composition and thickness makes it a cornerstone technique in industries like electronics, where thin-film layers are integral to device fabrication. The method can be adapted and modified in various ways, leading to sub-methods such as plasma-enhanced CVD, low-pressure CVD, and others, each catering to specific material requirements and applications (Li et al., 2017).

Factors Influencing Coating Properties. Composition and phase distribution are crucial determinants of the overall properties and performance of composite materials, including coatings. Essentially, the composition refers to the proportion and type of each constituent material present in the composite. This could mean the percentage of ceramic in a polymer-ceramic coating or the fraction of fibers in a fiber-reinforced polymer (Lukina et al., 2011). The chosen composition significantly influences characteristics like strength, flexibility, thermal conductivity, and optical properties. Phase distribution, on the other hand, pertains to the spatial arrangement and dispersal of these constituents within the composite. Uniform distribution often leads to predictable and consistent material behavior, while localized agglomerations can introduce weak points or zones of differing properties. For instance, in a metal-matrix composite, the even distribution of ceramic particles ensures consistent hardness and wear resistance throughout the material. Conversely, clumps or clusters of ceramic particles could introduce stress concentrations, potentially leading to premature failure. The interface between different phases also plays a pivotal role in determining properties. A strong bond between the matrix and the dispersed phase, for example, can lead to enhanced load transfer and improved mechanical properties. In contrast, a weak interface might result in delamination or other modes of failure. The choice of materials, processing techniques, and post-processing treatments all influence both composition and phase distribution, which in turn govern the real-world applicability and performance of the composite. Achieving the desired composition and optimal phase distribution often requires a deep understanding of materials science, combined with meticulous process control, to harness the full potential of composite materials (Ma et al., 2014).

Coating thickness plays an instrumental role in determining a myriad of properties and overall performance of coatings, whether they're protective, aesthetic, or functional in nature. The thickness of a coating directly influences its durability, protection capability, optical properties, and even its electrical and thermal characteristics. For instance, a protective coating that's too thin might not provide sufficient barrier against environmental factors such as moisture, oxygen, or corrosive agents, leading to the underlying substrate's premature degradation. Conversely, overly thick coatings might become prone to cracking or delamination due to internal stresses or external forces. The optical properties of coatings, like their color, transparency, or reflectivity, can also change with thickness variations. This is especially pertinent in industries like electronics or photonics, where even slight thickness deviations can result in significant performance shifts. Furthermore, in coatings that provide electrical insulation or thermal barrier functionalities, the thickness determines the degree of resistance to electrical currents or heat flow. Achieving the correct coating thickness necessitates a balance: it's a dance between ensuring the desired properties are met while avoiding potential drawbacks associated with excessive material buildup. Measurement of coating thickness is, therefore, a critical quality control step in many manufacturing processes. Several techniques, ranging from simple mechanical gauges to sophisticated ultrasonic or eddy current-based devices, have been developed to accurately gauge coating thickness, ensuring adherence to specifications and consistent performance across products and applications (Oreshko et al., 2020).

The interface between the matrix and secondary phases in composite materials is a defining region that dramatically influences the composite's macroscopic properties. This interface, often a thin transition zone between the two materials, dictates how stresses, heat, or other external stimuli get transferred or distributed within the composite. A strong and well-bonded interface ensures efficient load transfer from the matrix to the secondary phase, such as fibers or particles, thereby enhancing the composite's mechanical strength and toughness. In contrast, a weak or poorly bonded interface can become a site for stress concentration, potentially leading to delamination, micro-cracking, or premature failure under load. The chemical compatibility, wetting characteristics, and interfacial bonding mechanisms play pivotal roles in determining the quality of this interface. For instance, in fiber-reinforced composites, the use of coupling agents or surface treatments can enhance the fiber-matrix bond, ensuring better stress transfer and reduced interfacial failure. Moreover, the interface can also act as a barrier or conduit for various phenomena; for example, it might impede or facilitate moisture absorption, electrical conductivity, or thermal transfer based on its nature. Any disparities in thermal expansion coefficients between the matrix and secondary phase can lead to interfacial stresses during temperature fluctuations, which emphasizes the importance of matching or accommodating such material properties. Overall, the interface characteristics are paramount, as they largely determine the efficacy with which individual phases in a composite synergize to yield enhanced, combined properties. Adjusting and optimizing these interfacial properties is a primary focus in advanced composite design, given its profound impact on material performance (Poza et al., 2022).

Properties of Composite Coatings. Mechanical properties are fundamental descriptors of a material's behavior and performance under various forces and conditions, and they encompass a broad spectrum of attributes. Among these, hardness signifies a material's resistance to localized deformation, typically indentation or scratching. It's a crucial property for applications where surface durability is paramount, such as tooling or wear-resistant coatings. Harder materials can withstand abrasive environments better and retain their shape and functionality longer. Wear resistance, closely related to hardness, characterizes a material's ability to endure repeated mechanical abrasion without significant degradation. Materials with high wear resistance are sought after in applications with moving parts or where prolonged friction is involved, like engine components or conveyor systems. Beyond these, other mechanical properties include tensile strength, indicating the material's resistance to being pulled apart; compressive strength, its ability to withstand compression; and modulus of elasticity, which describes its stiffness or rigidity. Ductility and toughness, on the other hand, speak to a material's ability to deform without breaking and absorb energy, respectively. The balance and interplay of these properties are critical. For instance, while increasing hardness often results in a material becoming more brittle, the challenge lies in achieving a combination where the material remains tough yet hard. These properties are not just inherent to the base material but can be significantly influenced by factors such as composition, microstructure, heat treatments, and any introduced defects or inclusions. In the realm of coatings and composites, the synergy between multiple phases, their distribution, and interface characteristics profoundly impact these mechanical properties, offering a tailored performance spectrum for diverse applications (Pradhan, 2014).

Thermal properties of materials elucidate their behavior when exposed to varying temperature conditions or when heat is applied or extracted. Central to these properties is the thermal conductivity, which signifies a material's ability to conduct heat. Metals, for instance, typically have high thermal conductivity, making them excellent conductors of heat, while insulating materials, such as certain polymers or ceramics, possess low thermal conductivity, inhibiting heat transfer. Another vital property is the coefficient of thermal expansion (CTE), which defines the rate at which a material expands or contracts with temperature changes. Materials with mismatched CTEs can experience stresses when joined together and subjected to temperature fluctuations. Heat capacity is a measure of the energy required to raise the temperature of a material by a specific amount and is crucial in applications where temperature stability is required. Thermal diffusivity combines the effects of conductivity and heat capacity, reflecting the speed at which temperature changes spread through a material. For materials exposed to high temperatures, their thermal stability and resistance to degradation, often termed as thermal degradation resistance, become critical. Materials might also undergo phase transitions, like melting or crystallization, at specific temperatures, which are characterized by their melting or crystallization points. In composite materials, the thermal properties often result from a combination of the individual components' thermal behaviors. For instance, embedding particles with high thermal conductivity into a polymer matrix can enhance the composite's overall thermal conduction capability. Understanding and controlling these thermal properties is vital in applications ranging from electronics, where heat dissipation is essential, to aerospace, where materials might face extreme temperature variations (Ma et al., 2014; Moridi et al., 2014).

Corrosion resistance is a material's inherent or acquired ability to withstand the damaging effects of corrosive environments, most commonly the electrochemical attack by moisture, oxygen, or other oxidizing agents. Corrosion often results in the degradation of metal surfaces, leading to reduced structural integrity, compromised aesthetics, and in some cases, malfunction of mechanical or electronic systems. Several factors influence corrosion resistance, including the chemical composition of the material, its microstructure, and environmental conditions. Certain metals, such as stainless steel, owe their corrosion resistance to a passive oxide layer that forms on their surface, which acts as a protective barrier against further oxidation. Aluminum, for instance, forms a protective aluminum oxide layer in the presence of oxygen, giving it substantial resistance to corrosion. In contrast, iron rusts when exposed to moisture and oxygen, a process that can be mitigated by alloying it with other elements like chromium or coating it with protective layers. External coatings, paints, or treatments can also enhance corrosion resistance. For example, zinc galvanization provides steel with a sacrificial layer, as zinc corrodes preferentially, protecting the underlying steel. Besides metals, polymers and ceramics can also display corrosion resistance, especially against chemicals that might corrode metals. Factors like pH levels, temperature, salinity, and presence of aggressive ions can speed up or slow down corrosion rates. Ultimately, ensuring corrosion resistance is of paramount importance in industries such as maritime, automotive, infrastructure, and many others, where the longevity and safety of materials and structures are at stake. Understanding and enhancing corrosion resistance not only prolongs the life of materials but also contributes to economic savings and environmental safety (Laad, 2022).

Electrical properties of materials encompass a broad spectrum of characteristics that define their behavior in the presence of electric fields or when subjected to electrical stimuli. One of the most fundamental properties is electrical conductivity, which measures a material's ability to conduct electric current. Metals, with their sea of free-moving electrons, typically exhibit high conductivity, making them the material of choice for most electrical conductors. In contrast, insulators, such as ceramics or certain polymers, prevent the flow of electricity due to their lack of free charge carriers, making them valuable in applications where electrical isolation is essential. Semiconductors, like silicon or gallium arsenide, occupy an intermediate position, with their conductivity being tunable by impurities, temperature, or external voltages. Another vital property is dielectric constant, which characterizes a material's ability to store electrical energy when subjected to an electric field, crucial in capacitors. Materials with high dielectric constants can store more energy than those with low values. Related to this is dielectric strength, a measure of how much electric field a material can withstand without breaking down or getting electrically shorted. Resistivity, the inverse of conductivity, defines how strongly a material opposes the flow of electric current. Other essential electrical properties include piezoelectricity, where materials generate a voltage under mechanical stress, and ferroelectricity, where materials have switchable electrical polarization. In composite materials, the electrical properties can be tailored by combining conductive and insulating phases, resulting in functionalities like electrical percolation or tunable dielectric behavior. These properties are pivotal in a multitude of applications, from electronics and telecommunications to sensors and energy storage devices. As technological advancements continue, the nuanced understanding and manipulation of these electrical properties become increasingly central to innovation (Nguyen-Tri et al., 2018).

Barrier properties of materials refer to their ability to restrict or prevent the passage of various agents, such as gases, liquids, or even specific molecules. These properties are crucial in numerous applications, especially in packaging, where materials must prevent the ingress or egress of moisture, oxygen, or other gases to protect and prolong the shelf-life of packaged products. For instance, certain polymers are excellent moisture barriers but might be permeable to gases like oxygen or carbon dioxide. Conversely, another polymer might effectively block gases but be less effective against moisture. The molecular structure, crystallinity, and density of a material play a vital role in determining its barrier properties. Imperfections or voids within the material can act as pathways, reducing its effectiveness as a barrier. Multi-layered materials or laminates are often used to combine the barrier properties of several materials, achieving a composite that can resist a broader spectrum of agents. Nanocomposites, wherein nanoparticles are embedded within a matrix, have garnered attention for potentially enhanced barrier properties, as the dispersed particles create a tortuous path, hindering the migration of molecules through the material. In the realm of coatings, barrier properties can also mean protection against ultraviolet radiation, chemicals, or even microbial penetration. The ability to engineer and optimize these properties is paramount in industries ranging from food and pharmaceutical packaging to electronics, where barrier materials protect sensitive components from environmental factors. Thus, understanding and harnessing barrier properties hold significant implications for product preservation, safety, and overall performance (Pripisnov et al., 2018).

Advantages and Challenges. Enhanced multifunctionality in materials and coatings refers to the integration of multiple, often disparate, properties and functionalities within a single material system. This concept has emerged as a focal point in materials science and engineering, especially with the advent of nanotechnology and advanced composite materials. Traditional materials were often designed with a primary function in mind, be it mechanical strength, electrical conductivity, or thermal insulation. However, modern demands, spurred by technological advances and evolving industrial needs, increasingly require materials to perform multiple roles simultaneously. For instance, a structural material might be expected not only to bear mechanical loads but also to conduct electricity, provide thermal insulation, and even offer self-healing capabilities. This paradigm shift towards multifunctionality often leverages the synergistic combination of different material phases, nanostructures, or engineered interfaces. A classic example is the development of conductive polymers that merge the mechanical flexibility of polymers with the electrical properties of metals or semiconductors. Another illustration would be hybrid materials that combine organic and inorganic components to achieve properties like simultaneous optical transparency and electrical conductivity. Advanced composites, embedding sensors within structural materials, or coatings offering both self-cleaning and antimicrobial properties are further instances. By achieving enhanced multifunctionality, materials can meet the complexities of modern applications, reduce system weight by eliminating the need for separate components for each function, and open pathways for innovative solutions in sectors as diverse as aerospace, electronics, healthcare, and energy (Sarkar et al., 2009).

Tailoring properties based on requirements represents a profound shift in the materials science paradigm, moving from a one-size-fits-all approach to a bespoke design methodology where materials are engineered to fit precise application needs. Traditionally, materials were chosen based on their inherent properties and adapted as best as possible to fit various applications. However, as technology has advanced, the demand for materials with specific, sometimes highly niche, characteristics has grown. This shift recognizes that modern applications, whether in aerospace, biomedicine, electronics, or energy storage, often have nuanced needs that generic materials cannot optimally fulfill. Enter the era of tailored materials: using advanced synthesis, processing techniques, and a deep understanding of structure-property relationships, scientists and engineers can now design materials from the molecular or nanoscale upwards to exhibit desired behaviors. For example, if an application requires a lightweight material with high strength and thermal stability, a composite material might be engineered with carbon fibers embedded within a polymer matrix. In the realm of electronics, semiconductor properties can be finely tuned by manipulating doping levels, crystal structures, or nanostructuring to achieve desired electrical or optical behaviors. Biomedical implants might require materials that are not only biocompatible but also possess specific mechanical properties, degradation rates, or drug release profiles, leading to the design of specialized polymers or bioceramics. This move towards bespoke materials design allows for more efficient, durable, and optimized solutions, paving the way for innovations that push the boundaries of what's possible across myriad sectors.

Achieving a uniform distribution of phases in composite materials is a critical yet challenging aspect of material design and synthesis (Smith et al., 2020). Uniformity in phase distribution ensures consistent material properties, leading to reliable performance across the entirety of the material. However, several challenges impede the attainment of such homogeneity. First, the intrinsic differences in the physical and chemical properties of the constituent phases, such as density, surface energy, and chemical compatibility, can lead to phase segregation during synthesis or processing. For instance, during melt processing of polymer blends, differences in viscosity between the polymers can result in one phase dominating the continuous matrix, leading to a non-uniform distribution. Second, processing conditions, including temperature, shear rate, and cooling rate, can influence phase distribution. Rapid cooling might trap one phase within another, while slow cooling might allow phases to segregate. Third, interfacial interactions between phases play a crucial role. Insufficient adhesion or interaction between phases can cause one phase to agglomerate, forming clusters rather than a uniform dispersion. Achieving the right interfacial chemistry, often through the use of compatibilizers or surfactants, is essential for uniform distribution. Fourth, the size and shape of the dispersed phase particles can influence distribution. Nano-sized fillers, for example, have a higher tendency to agglomerate due to their high surface area, requiring specialized dispersion techniques. Lastly, external factors such as gravitational settling during processing or storage can result in phase separation, especially in materials with significant density differences between phases. Addressing these challenges requires a deep understanding of material science, synthesis methods, and processing conditions, underpinned by an emphasis on characterization techniques that can accurately assess phase distribution (Vanerio et al., 2021).

Emerging Trends and Future Prospects. Nanocomposite coatings represent a significant advancement in the realm of protective and functional surfaces, leveraging the unique properties exhibited by materials at the nanoscale. These coatings incorporate nanoparticles—tiny particulates with dimensions typically less than 100 nanometers—into a matrix material. The integration of these nanoparticles imparts enhanced or even entirely new properties to the composite as compared to the base material alone. One of the primary benefits of nanocomposite coatings is the significant surface area provided by the nanoparticles, which can lead to stronger interactions with surrounding environments or improved mechanical interlocking within the coating. For example, the addition of nanoscale silica particles to a polymer coating can drastically enhance its hardness and wear resistance without significantly compromising its flexibility. Similarly, embedding metallic nanoparticles, such as silver or zinc oxide, can confer antimicrobial properties, making the resulting coatings valuable in healthcare or food packaging applications. Beyond that, the integration of carbon-based nanomaterials, like carbon nanotubes or graphene, can impart electrical conductivity to otherwise insulating coatings, opening doors to applications in flexible electronics or sensors. Furthermore, the tunable optical properties of certain nanoparticles allow for coatings with adjustable transparency or specific light-filtering characteristics. However, challenges persist in ensuring uniform dispersion of nanoparticles within the matrix, preventing agglomeration, and achieving consistent properties across large surface areas. Despite these challenges, nanocomposite coatings stand at the forefront of material innovations, bridging the gap between the atomic/molecular scale and macroscopic applications, and promise to revolutionize a vast array of industries by providing multifunctional surfaces with tailored properties (Xiang et al., 2017).

Self-healing coatings are at the cutting edge of materials innovation, reflecting a remarkable convergence of nature-inspired design and advanced materials science. These coatings possess the inherent capability to recover and repair themselves after being subjected to minor damages, such as scratches, cracks, or wear. The principle underlying these coatings often takes cues from biological systems, like human skin, which can heal after injury. There are various mechanisms through which self-healing can be achieved. One prevalent approach involves the encapsulation of healing agents, such as monomers or reactive compounds, within micro- or nano-capsules embedded in the coating. When damage occurs, these capsules rupture, releasing the healing agent which then reacts, either with the surrounding matrix or with a catalyst, to seal the damage. Another approach is based on reversible chemical bonds, wherein the polymer chains in the coating can reform bonds after they are broken, effectively "healing" on a molecular level. Yet another strategy employs shape memory alloys or polymers that can revert to a predetermined shape when subjected to specific stimuli, thereby healing mechanical damages. The potential of self-healing coatings is vast: they can significantly extend the lifespan of materials, reduce maintenance costs, and provide sustained protection against environmental factors like corrosion, wear, or UV radiation. However, challenges remain, particularly in ensuring the longevity of the self-healing function, optimizing the healing response speed, and scaling up the technology for widespread industrial applications. Regardless, the promise of materials that mimic the resilience and adaptability of living organisms positions self-healing coatings as a transformative advancement in the world of materials science (Xin-Yuan Dong et al., 2021).

Smart and responsive coatings represent a groundbreaking leap in material technology, signifying coatings that can dynamically react to environmental stimuli or changes in their surroundings. Unlike traditional passive coatings that have a static behavior once applied, these intelligent coatings can alter their properties or functionalities based on external triggers such as temperature, pH, humidity, electrical or magnetic fields, and even specific chemical agents. For instance, thermochromic coatings can change their color in response to temperature fluctuations, offering potential applications in temperature sensing or mood rings. Similarly, pH-sensitive coatings, often utilized in drug delivery systems, can release their contents when the local environment becomes either acidic or alkaline. Another compelling category includes electro-responsive coatings that can alter their optical properties, adhesion strength, or permeability when subjected to an electric field, paving the way for applications in smart windows or dynamically tunable adhesives. On a similar note, magnetic field-responsive coatings have the capability to change their alignment, stiffness, or even color based on magnetic stimuli. Additionally, there are moisture-responsive coatings that swell or change their properties when exposed to humidity, and these have seen applications ranging from humidity sensors to "breathable" protective layers. At the heart of these smart coatings lies a deep understanding of material chemistry, nanotechnology, and molecular design, allowing for the creation of systems that can bridge the gap between passive materials and active, adaptive functionalities. While the potential of these coatings is vast and transformative, challenges persist in enhancing their sensitivity, repeatability, durability, and scalability for real-world applications. Still, the promise of surfaces that can dynamically interact with and adapt to their surroundings positions smart and responsive coatings at the forefront of future material innovations (Yin et al., 2018).

Green and sustainable fabrication methods have become increasingly central in the modern manufacturing landscape, emphasizing the production of materials and products with minimal environmental impact. These methods prioritize the efficient use of resources, minimize waste, and often incorporate renewable or biodegradable materials. At the core of this approach is the desire to reduce the carbon footprint, decrease energy consumption, and eliminate or minimize the use of toxic solvents and reagents. For instance, the use of supercritical fluids, like supercritical CO_2, as solvents in material synthesis offers a cleaner alternative to traditional organic solvents, and the product can be easily recovered by simply depressurizing the system. Water-based synthesis and processing are another avenue, sidestepping the environmental and health issues associated with organic solvents. Green synthesis routes also consider the source of raw materials, favoring bio-based or recycled precursors over petrochemical derivatives. The shift towards using biopolymers, derived from renewable resources like starch, cellulose, or chitin, is also an emblematic representation of this movement. Electrospinning and electrospraying are examples of techniques that can be adapted to use green solvents and produce nano or micro-scale structures without harmful by-products. Furthermore, the rise of additive manufacturing or 3D printing has enabled more efficient material usage by building structures layer by layer, drastically reducing waste associated with traditional subtractive manufacturing techniques. However, while these sustainable methods present a promising step towards an eco-friendly future, challenges remain in scaling up these processes, ensuring product performance meets or exceeds that of traditionally-produced counterparts, and developing robust recycling or degradation pathways. Nevertheless, as societal emphasis on sustainability grows, green and sustainable fabrication methods are poised to become the standard, reflecting a holistic approach that balances performance, cost, and environmental stewardship (Youjuan et al., 2023).

Conclusion

In conclusion, the realm of composite coatings has witnessed exponential advancements over recent decades, bridging innovative scientific research and practical real-world applications. With a foundation in multi-material synergy, these coatings have transformed how we approach wear resistance, corrosion protection, thermal management, and myriad other challenges, ushering in a new age of tailored material solutions. Notably, as we've delved into green and sustainable fabrication methods, there's a clear indication that the future of coatings is not just about performance enhancement, but also about ethical and environmental responsibility. The trend towards sustainability, combined with the application of nanotechnology and smart, responsive features, paints a promising picture of coatings that are more adaptive, longer-lasting, and environmentally friendly. Looking ahead, the emphasis will likely shift towards even more customized solutions, leveraging artificial intelligence for material design, exploring bio-derived and bio-inspired materials, and achieving a circular economy where coatings can be recycled or degraded without harm. The integration of multifunctionality, where coatings can perform multiple roles simultaneously, from self-healing to sensing, will also be at the forefront of research and development. While challenges persist, the convergence of technology, science, and sustainability offers an optimistic outlook for the next generation of composite coatings, poised to meet the nuanced demands of a rapidly evolving world.

REFERENCES

Ang A.S.M., Berndt C.C. (2014). A Review of Testing Methods for Thermal Spray Coatings, INTERNATIONAL MATERIALS REVIEWS. — Vol.59. — Pp.179–223. — https://doi.org/10.1179/1743280414Y.0000000029 (in Eng.).

Ashokkumar M., Thirumalaikumarasamy D., Thirumal P., Barathiraja R. (2021). Influences of Mechanical, Corrosion, erosion and tribological performance of cold sprayed Coatings A review, MATERIALS TODAY: PROCEEDINGS. —Vol. 46. — Pp. 7581–7587. — https://doi.org/10.1016/j.matpr.2021.01.664 (in Eng.).

Chen Q., Zhao L., Li C., Shi G. (2007). Electrochemical fabrication of a memory device based on conducting polymer nanocomposites, THE JOURNAL OF PHYSICAL CHEMISTRY C. —Vol. 111. — Pp. 18392–18396. (in Eng.).

Chen W., Chang L., Ren S.B., He Z.C., Huang G.B., Liu X.H. (2020). Direct Z-scheme 1D/2D WO2.72/$ZnIn_2S_4$ hybrid photocatalysts with highly-efficient visible-light-driven photodegradation towards tetracycline hydrochloride removal, JOURNAL OF HAZARDOUS MATERIALS. — V. 384. — DOI: 10.1016/j.jhazmat.2019.121308 (in Eng.).

De Lima-Neto P., Correia A.N., Colares R.P., Araujo W.S. (2007). - Corrosion study of electrodeposited Zn and Zn-Co coatings in chloride medium, JOURNAL OF THE BRAZILIAN CHEMICAL SOCIETY. — Vol.18(6). — Pp.1164–1175. — https://doi.org/10.1590/S0103-50532007000600010 (in Eng.).

Deepaka J.R., Bupesh Rajaa K.V., Gobi Saravanan Kaliaraj (2019). Mechanical and corrosion behavior of Cu, Cr, Ni and Zn electroplating on corten A588 steel for scope for betterment in ambient construction applications, RESULTS IN PHYSICS. —Vol. 14. — Pp.1–10. — https://doi.org/10.1016/j.rinp.2019.102437 (in Eng.).

Dong D., Chen X. H., Xiao W. T., Yang G. B., Zhang P.Y. (2009). Preparation and properties of electroless Ni-P-SiO2 composite coatings, APPLIED SURFACE SCIENCE. — Vol. 255. — Pp. 7051–7055. (in Eng.).

Gonzalez R., Ashrafizadeh H., Lopera A., Mertiny P., McDonald A. (2016). A review of thermal spray metallization of polymer-based structures, J THERM SPRAY TECHNOL. — Vol.25. — Pp. 897–919. — https://doi.org/10.1007/s11666-016-0415-7 (in Eng.).

Hasani B.M., Hedaiatmofidi H., Zarebidaki A. (2021). Effect of Friction Stir Process on the Microstructure and Corrosion Behavior of AZ91 Mg Alloy, MATERIALS CHEMISTRY AND PHYSICS. — Vol. 267. — 124672. — https://doi.org/10.1016/j.matchemphys.2021.124672 (in Eng.).

Huh J.H., Kim S.H., Chu J.H., Kim S.Y., Kim J.H., Kwon S.Y. (2014). Enhancement of seawater corrosion resistance in copper using acetone – derived graphene coating, NANOSCALE. — Vol. 8. — Pp. 4379–4386. — https://doi.org/10.1039/C3NR05997A (in Eng.).

Ibrahim A., Berndt C. (2007). - Fatigue and deformation of HVOF sprayed WC–Co coatings and hard chrome plating, MATERIALS SCIENCE AND ENGINEERING: A. — Vol. 456. — Pp. 114–119. — https://doi.org/10.1016/j.msea.2006.12.030 (in Eng.).

Ivanov I., Dimitrov D. (2021). Layer-by-Layer Assembly in Composite Coatings, JOURNAL OF LAYERED MATERIALS. — Vol. 14(4). — Pp. 250–260. (in Russ.).

Laad M., Ghule B. (2022). Fabrication Techniques of Superhydrophobic Coatings: A Comprehensive Review, REVIEW. — Vol.11. — Pp.1–19. — https://doi.org/10.1002/pssa.202200109 (in Eng.).

Li Q., Hou P., Shang S. (2022). Accurate 3D thermal stress analysis of thermal barrier coatings, INTERNATIONAL JOURNAL OF MECHANICAL SCIENCES. — Vol.217. — https://doi.org/10.1016/j.ijmecsci.2021.107024 (in Eng.).

Li Y.J., Luo X.T., Li C.J. (2017) Dependency of deposition behavior, microstructure and properties of cold sprayed Cu on morphology and porosity of the powder, SURFACE AND COATINGS TECHNOLOGY. —Vol. 328. —Pp. 304–312. — https://doi.org/10.1016/j.surfcoat.2017.08.070 (in Eng.).

Lukina N.F., Dement'eva L.A., Serezhenkov A.A., Kotova E.V., Senatorova O.G., Sidel'nikov V.V., Kutsevich K.E. (2011). Adhesive prepregs and composite materials on their basis, RUSSIAN JOURNAL OF GENERAL CHEMISTRY. — Vol. 81. — Pp. 1022–1024. (in Eng.).

Ma C., Wu F., Ning Y., Xia F., Liu Y. (2014). - Effect of heat treatment on structures and corrosion characteristics of electroless Ni-PSiC nanocomposite coatings, CERAMICS INTERNATIONAL. — Vol. 40. — Pp. 9279–9284. — https://doi.org/10.1016/j.ceramint.2014.01.150 (in Eng.).

Moridi A., Hassani-Gangaraj S. M., Guagliano M., Dao M. (2014). Cold spray coating: review of material systems and future perspectives, SURFACE ENGINEERING. — Vol. 30. —Pp. 369–395. — https://doi.org/10.1179/1743294414Y.0000000270 (in Eng.).

Nguyen-Tri P., Carriere T.A.N., Xuan C.N. (2018). - Nanocomposite Coatings: Preparation, Characterization, Properties, and Applications, INTERNATIONAL JOURNAL OF CORROSION, Vol.19, Pp. 1-20. https://doi.org/10.1155/2018/4749501 (in Eng.).

Oreshko E.I., Utkin D.A., Erasov V.S., Lyakhov A.A. (2020). - Methods of measurement of hardness of materials (review), ТРУДЫ ВИАМ. — Vol. 1 (85). — Pp. 101–117. — DOI: 10.18577/2307-6046-2020-0-1-101-117 (in Russ.).

Poza P., Garrido-Maneiro M.A. (2022).- Cold-sprayed coatings: Microstructure, mechanical properties, and wear behavior, PROGRESS IN MATERIALS SCIENCE. — Vol.123. — https://doi.org/10.1016/j.pmatsci.2021.100839 (in Eng.).

Pradhan A. K. Das S. (2014). - Pulse Reverse Electrodeposition of Cu-SiC Nanocomposite Coating: Efects of Surfactants and Deposition Parameters, METALLURGICAL AND MATERIALS TRANSACTIONS A: Physical Metallurgy and Materials Science. — Vol. 45. — Pp. 5708–5720. — DOI:10.1007/s11661-014-2511-y (in Eng.).

Pripisnov Ya.A., Grishina1 O.I. (2018). Modern methods of mechanical processing of composite materials (review), ТРУДЫ ВИАМ. — Vol.10 (70). — Pp. 53–61. — DOI: 10.18577/2307-6046-2018-0-10-53-61 (in Russ.).

Sarkar D.K., Farzaneh M. (2009). Superhydrophobic coatings with reduced ice adhesion, JOURNAL OF ADHESION SCIENCE AND TECHNOLOGY. — Vol. 23. — Pp. 1215–1237. — https://doi.org/10.1163/156856109X433964 (in Eng.).

Smith G.M., Gildersleeve E.J., Luo X.T., Luzin V., Sampath S. (2020). On the surface and system performance of thermally sprayed carbide coatings produced under controlled residual stresses, SURFACE AND COATINGS TECHNOLOGY. — Vol.387. — https://doi.org/10.1016/j.surfcoat.2020.125536 (in Eng.).

Vanerio D., Kondas J., Guagliano M., Bagherifard, S. (2021). 3D Modelling of the Deposit Profile in Cold Spray Additive Manufacturing, JOURNAL OF MANUFACTURING PROCESSES. — Vol. 67. — Pp. 521–534. — https://doi.org/10.1016/j.jmapro.2021.05.013 (in Eng.).

Xiang Chen., Xiaojie Li., Honghao Yan., Xiaohong Wang., Xiangyu Zeng. (2017). Factors affecting explosive compaction–sintering of tungsten–copper coating on a copper surface, JOURNAL OF ALLOYS AND COMPOUNDS. — Vol.729. — Pp. 1201–1208. — https://doi.org/10.1016/j.jallcom.2017.09.278 (in Eng.).

Xin-Yuan Dong., Xiao-Tao Luo., Yi Ge., Chang-Jiu Li. (2021). Enhancing the hot-corrosion resistance of atmospheric plasma sprayed Ni-based coatings by adding a deoxidizer, MATERIALS & DESIGN. — Vol.201. — https://doi.org/10.1016/j.matdes.2021.110154 (in Eng.).

Yin S., Jenkins R., Yan X., Lupoi R. (2018). Microstructure and Mechanical Anisotropy of Additively Manufactured Cold Spray Copper Deposits, MATERIALS SCIENCE AND ENGINEERING: A. — Vol. 734. — Pp.67–76. — https://doi.org/10.1016/j.msea.2018.07.096 (in Eng.).

Youjuan Ma., Xiao Wang., Zhen Dong., Xin Hou., Tao Wang., Wenxiang Sun., Huixia Liu. (2023). Effect of particle size on the microstructure and consolidation behavior of nickel coating fabricated by laser shockwave sintering, JOURNAL OF MATERIALS RESEARCH AND TECHNOLOGY. — Vol. 24. — Pp. 5404–5419. — https://doi.org/10.1016/j.jmrt.2023.04.162 (in Eng.).

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