

PACS numbers: 81.05.Je, 87.19.xb, 87.85.Rs

Review on Recent Developments in Carbides' Nanoparticles for Antibacterial Applications

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The carbides' nanoparticles are characterized by a distinguish properties that make them appropriate for use in a variety of industrial and medicinal applications. Some of these unique characteristics of the carbides are high antibacterial and antimicrobial activities, chemically inert and high hardness. In this review, the properties, advantages, and limitations of carbides' nanoparticles for antibacterial applications are discussed. The carbides' nanoparticles for previous studies possess strong antimicrobial action against both gram-positive and gram-negative microorganisms.

Наночастинки карбідів характеризуються особливими властивостями, що роблять їх придатними для використання в різноманітних промислових та медичних застосуваннях. Деякими з цих унікальних характеристик карбідів є високі антибактеріальна й антимікробна активності, хемічна інертність і висока твердість. У цьому огляді обговорюються властивості, переваги й обмеження наночастинок карбідів для антибактеріального застосування. Наночастинки карбідів, згідно з попередніми дослідженнями, мають сильну антимікробну дію проти грамозитивних та грамнегативних мікроорганізмів.

Key words: carbides, nanoparticles, antibacterial range, gram-negative bacteria, gram-positive bacteria.

Ключові слова: карбіди, наночастинки, антибактеріальний спектр дії, грамнегативні бактерії, грамозитивні бактерії.

(Received 17 December, 2023)

1. INTRODUCTION

Because of their large surface area-to-volume ratio and the quantum

confinement effects, nanoscale particles are thought to be viable options for modern nanodevices [1]. Comprehensive research has been done on nanoparticles (NPs) in biomedical applications. Extensive studies on NPs in biomedical uses, such as biomaterials, diagnostics, and cancer treatment have been conducted [2]. NPs bind securely to microbial membranes because of their small size and large surface to volume proportion, which is essential for their antibacterial effectiveness [3]. Bacteria can be broadly categorized as either gram-positive or gram-negative. The arrangement of peptidoglycan, a crucial membrane component, accounts for the structural variations. The membrane of the cytoplasm and the outside membrane of gram-negative bacteria are separated by a very thin ($\cong 2-3$ nm) peptidoglycan layer, whereas gram-positive bacteria do not have an outer membrane and have a roughly 30-nm-thick peptidoglycan layer [4].

2. PROPERTIES OF NANOPARTICLES

In nanoscience and nanotechnology, the dimension of stuff that matters most commonly falls between 0.2 nm and 100 nm (nanoscale). When a substance gets closer to the nanoscale, its properties alter. Furthermore, a material-surface atom fraction starts to take on greater significance. Regardless of their size, bulk materials have comparatively constant physical properties; however, this is frequently not the case at the nanoscale. The fraction of atoms at the surface grows in relation to the whole amount of atoms in the bulk material, as the substance gets smaller. Because the material surface predominates over its bulk qualities, this can result in surprising properties of nanoparticles.

The enormous surface-to-volume ratios and discrete electrons' energy states of the materials at this size give rise to the distinctive mechanical, optical, magnetic, and electrical features of the nanomaterials. Generally speaking, the optical and electrical properties of both organic and inorganic substances change significantly from a bulk substance at the atomic and molecular levels as their sizes approach the nanoscale and are depending on their form and size. Observable size-dependent features include superparamagnetism in magnetic materials, surface plasmon resonance in noble metal particles, and quantum confinement in semi-conductor particles. Because of their enormous surface-to-volume ratio and crystalline surface structure, the nanoparticles exhibit exceptional properties. Furthermore, because of their highly active facets and ability to be synthesized to a specific specification, nanoparticles have an increased catalytic activity that makes them an appealing solution for solving a variety of technological issues.

Nanoparticles are being thoroughly investigated in the realm of medicine due to their size-dependent chemical and physical characteristics. Nanoparticles are comparable in size to the majority of biological molecules and structures. This makes them a compelling option for use in biomedical research, both *in vivo* and *in vitro*. Their use in specific drug delivery, visualization, detecting, and artificial implants has resulted from their integration with the medical industry. Their application as antimicrobial agents to combat extremely pathogenic and drug-resistant bacteria is a new intriguing direction for their research in medicine.

However, the biocompatibility is a highly attractive feature for the use of nanoparticles in biology. The capacity of a material to function medicinally without causing undesirable local or systemic consequences is known as biocompatibility [5].

3. ADVANTAGES OF NANOPARTICLES

In comparison to conventional delivery remedies, nanoparticles can provide a number of important benefits. Because of their surface features and particle size, nanoparticles can target drugs in both active and passive modes. Because of the way that using nanoparticles changes the drugs' organ distribution and subsequent clearance, there is a decrease in adverse effects and an increase in the therapeutic efficacy of the treatment. Additionally, nanoparticles regulate and maintain the drugs' release. It is simple to control the release and degradation characteristics of nanoparticles based on the selection of matrix ingredients. Another benefit of nanoparticles is their ability to target specific sites. It can be accomplished by applying targeted ligands on the particle surface. Nanoparticles can be administered intraocularly, parenterally, nasally, orally, *etc.* These nanoparticles also exhibit great stability, the capacity to transfer hydrophilic and hydrophobic molecules, a high surface area-to-mass ratio, high reactivity, extended systemic circulation, accurate medication targeting, and the simultaneous administration of numerous medicines [6].

4. THE DISADVANTAGES OF NANOPARTICLES

Despite all of these advantages, there are a number of disadvantages of nanoparticles [6]: physically manipulating nanoparticles in both liquid and dry states can be difficult due to particle-particle aggregation caused by their huge surface area and small size. Furthermore, the large surface area and small particle size readily result in burst release and minimal drug loading [6].

5. PROPERTIES AND APPLICATIONS OF CARBIDES

Carbides are significant substances due to their unique characteristics and variety of applications. The carbon compounds have the fewest electronegative components. Carbon compounds, such as phosphorus, nitrogen, sulphur, and oxygen, are not regarded as carbides [7]. These are their classifications as follow.

1. *Ionic or Salt-Like Carbides*. Ionic or salt-like carbides are used to describe the carbides of strongly electropositive elements including aluminium, alkali metals, and alkaline earth metals (calcium and aluminium carbides among other examples) [7].

2. *Transition Metal Carbides*. Due to their beneficial physical characteristics, such as their high melting points (for example, hafnium and tantalum carbides have the highest known melting temperatures of all substances), they have been intriguing active materials; additionally, they exhibit both excellent electrical conductivity and chemical stability, and commercial uses for transition metal carbides include cutting tools, gas turbine rotors, and protective coatings for fusion reactors [8].

3. *Interstitial Carbides*. Carbon atoms occupy the interstitial area inside the closely spaced array between metal atoms. These have high melting points and are quite hard. They are effective electrical conductors. These may be hydrolysed by diluted acids or by water [7].

4. *Covalent Carbides*. Metalloid substances, such as boron and silicon, create them. Between each atoms of the metalloid are covalent connections. These substances are unsolvable, chemically inert, and exceedingly hard [7].

Due to its high melting temperatures, high degree of hardness, resistance to oxidation, strong abrasion resistance, and heat shock resistance, carbides have been widely used in a variety of industries, including wear resistance, aerospace materials, and composite ceramic materials [9–13]. The characteristics and uses of binary carbides are mentioned in Table.

Potantin *et al.* [14] in 2018 created biocompatible ceramic compounds *via* combustion-mode synthesis in the system Ti–C–Co–Ca–(PO₄)₂–Ag–Mg. Investigations were done on how cobalt affected the structure, characteristics, and parameters of the mixtures' combustion. Compact ceramics are made up of localized calcium oxide (CaO) isolations, a uniformly distributed titanium phosphate (Ti₃·PO_x) phase along grain boundaries, and a composite grain frame made of nonstoichiometric titanium carbide (TiC_{0.5}–TiC_{0.6}). The addition of cobalt encourages the synthesis of the intricate intermetallic combination CoTiP and TiCo. A solid solution based on silver is created, when magnesium and silver are alloyed.

TABLE. A list of some binary carbides' features and uses [7].

Sr. No.	Molecular formula	Properties	Applications
1	WC	Abrasion resistant and very hard	Wear parts, fine drills, mining and cutting tools
2	Mo ₂ C	Insoluble in water	Cutting tools and coating material
3	ZrC	High melting point, inertness, polar covalent compound, and thermal conductivity	Used as an abrasive, refractory coating, and cladding material in nuclear reactors and thermophotovoltaic radiators
4	VC	Cubic crystal structure, excellent high temperature property and chemically stable	To improve the properties of cermet and arrange the mechanical properties of steel alloys, tungsten carbide is added
5	HfC	The most refractory material known to date is insoluble in water and has a low resistance to oxidation	Used in hard coatings
6	Co ₂ C	Its production is energetically favourable, it is strong metallic-compound and paramagnetic, and it has an orthorhombic structure	Used in the steam reformation of alcohols to produce hydrogen
7	TaC	Heavy dark colour powder that is extremely hard, barely soluble in acids, and has a metallic shine	As a coating, it serves as an inhibitor of grain growth and is used in the creation of sharp instruments and cutting tools

6. NANOPARTICLES FOR ANTIBACTERIAL

Antibacterial compounds are those that either directly kill or restrict the growth of germs in the vicinity without generally endangering adjacent tissue. Nowadays, most antibacterial drugs are made of chemically modified natural compounds like carbapenems, cephalosporins, and lactams (like penicillins). Furthermore, pure natural antibiotics like aminoglycosides and entirely synthetic antibiotics like sulphonamides are regularly used. Generally speaking, the agents fall into two categories: bactericidal ones, which destroy germs, and bacteriostatic ones, which stops bacteria from growing. Antibacterial medications are crucial in the fight against infectious diseases. Antibacterial antibiotic resistance has emerged frequently as a result of their widespread usage and abuse, which is a signifi-

cant issue. Resistance is typically the result of evolutionary processes during happens, for instance, antibiotic medication, and these processes result in inheritable resistance. Additionally, resistance may develop through horizontal gene transfer *via* conjugation, transduction, or transformation [15]. Each nanoparticle has a unique mechanism for its antibacterial activity. The antibacterial mechanism for all types of nanoparticles is not entirely known. Some theoretical processes focus on the fast release of antibacterial metal ions from the surfaces of the nanoparticles, while others are related to the physical properties of these nanoparticles (membrane-damaging abrasiveness of the nanoparticle). Increased material contact with the environment is made possible by the growing specific surface area of a dosage of nanoparticles as the particle size decreases.

Consequently, increasing the surface-to-volume ratio of naturally antibacterial materials enhances their antibacterial effect. Because of this, a nanoparticle composed of an intrinsically antibacterial material may show antibacterial activity in a number of ways, such as the release of antibacterial metallic ions from the particle surface and the antibacterial physical properties of the nanoparticle, such as membrane damage or cell wall penetration. By comparing the outcomes of numerous trials, it is possible to determine characteristics of nanoparticles, which are most crucial for developing the ideal antibacterial particle. One of the most significant factors influencing antibacterial activity is chemistry, followed by particle size, shape, and zeta-potential [16].

7. CONCLUSION

Carbides nanoparticles are considered actually promising materials in environmental, medical, and industrial applications, which are attributed to the optimum properties of carbides. According to the review, metal ion release, cell wall penetration, or membrane disruption are three main ways, in which nanoparticles work. The carbides' nanoparticles exhibit strong antibacterial activity against both positive-gram and negative-gram bacteria.

REFERENCES

1. M. A. Raza, Z. Kanwal, S. Riaz, and S. Naseem, Synthesis, Characterization and Antibacterial Properties of Nano-Sized Cobalt Particles. *The 2016 World Congress on Advances in Civil, Environmental, and Materials Research (August 28–September 1, 2016, Korea: 2016)*; <https://api.semanticscholar.org/CorpusID:115147588>
2. Y.-Ki Cheong, J. C. Castro, L. Ciric, M. Edirisinghe, E. C.-Green,

- U. E. Illangakoon, Q. Kang, S. Mahalingam, R. K. Matharu, R. M. Wilson and G. Ren, *Nanomaterials*, **7**, No. 7: 152 (2017); doi:10.3390/nano7070152
3. H. A. Alhadrami, A. Baqasi, J. Iqbal, R. A. M. Shoudri, A. M. Ashshi, E. I. Azhar, F. Al-Hazmi, A. Al-Ghamdi, and S. Wageh, *American Journal of Nanomaterials*, **5**, No. 1: 31 (2017); doi:10.12691/ajn-5-1-5
 4. Mritunjai Singh, Shinjini Singh, S. Prasad, and Indrajeet Singh Gambhir, *Digest Journal of Nanomaterials and Biostructures*, **3**, No. 3: 115 (2008); https://www.researchgate.net/publication/256463087_Nanotechnology_in_medicine_and_antibacterial_effect_of_silver_nanoparticles
 5. Ravishankar Rai Vittal and Jamuna Bai Aswathanarayan, Nanoparticles and Their Potential Application as Antimicrobials, Science against Microbial Pathogens: Communicating Current Research and Technological Advances (Ed. A. Méndez-Vilas). *Formatex, Microbiology Series*, **1**, No. 3: 197 (2011); https://www.researchgate.net/publication/267767207_Nanoparticles_and_their_potential_application_as_antimicrobials
 6. S. Patel, D. Singh, S. Srivastava, M. Singh, K. Shah, D. Nandini Chauahn, N. S Chauhan, *Advances in Pharmacology and Pharmacy*, **5**, No. 3: 31 (2017); doi:10.13189/app.2017.050301
 7. S. Vats, R.Sharma, and N. Prasad, Properties, *Journal of Chemical and Pharmaceutical Research*, **10**, No. 3: 190 (2018); <https://api.semanticscholar.org/CorpusID:202724333>
 8. Y. Zhong, X. Xia, F. Shi, J. Zhan, J. Tu, and H. J. Fan, *Adv. Sci.*, **3**, No. 5: 1 (2016); <https://doi.org/10.1002/advs.201500286>
 9. A. Al-Ghaban, K. M. Shabeeb, and A. H. Hamaza, *Journal of Advanced Physics*, **6**, No. 3: 367 (2017); <https://doi.org/10.1166/jap.2017.1334>
 10. A. Al-Ghaban, K. M. Shabeeb, and A. H. Hamaza, *Advances in Natural and Applied Sciences*, **10**, No. 12: 94 (2016), [https://www.researchgate.net/publication/309463507_Synthesis_and_Characterization_of_TiC-Al₂O₃_Nanoparticles](https://www.researchgate.net/publication/309463507_Synthesis_and_Characterization_of_TiC-Al2O3_Nanoparticles)
 11. A. Al-Ghaban, K. M. Shabeeb, and A. H. Hamaza, *Journal of Applied Sciences Research*, **12**, No. 5: 64 (2016); [https://www.researchgate.net/publication/309463406_Effect_of_NanoZrO₂_Addition_on_the_Structural_and_Mechanical_Properties_of_TiC](https://www.researchgate.net/publication/309463406_Effect_of_NanoZrO2_Addition_on_the_Structural_and_Mechanical_Properties_of_TiC)
 12. A. Al-Ghaban, K. M. Shabeeb, and A. H. Hamaza, *Materials Focus*, **6**, No. 1: 15 (2016); doi:10.1166/mat. 2016.1373
 13. A. Al-Ghaban, K. M. Shabeeb, and A. H. Hamaza, *Materials Focus*, **6**, No. 1: 65 (2018); <https://doi.org/10.1166/mat.2018.1477>
 14. A. Yu. Potanin, Yu. S. Pogozhev, A. V. Novikov, E. A. Levashov, N. A. Kochetov, and N. V. Litovchenko, *Russian Journal of NonFerrous Metals*, **59**, No. 3: 323 (2018); <https://doi.org/10.3103/S1067821218030112>
 15. M. J. Hajipour, K. M. Fromm, A. A. Ashkarran, D. J. de Aberasturi, I. R. de Larramendi, T. Rojo, V. Serpooshan, W. J. Parak, and M. Mahmoudi, *Trends in Biotechnology*, **30**, No. 10: 499 (2012); doi:10.1016/j.tibtech.2012.06.004
 16. S. Nas Farouk, Ali Muhammadi, and Muhammad A. Aminu, *Arch Nano Op. Acc. J.*, **1**, No. 3: 59 (2018); doi:10.32474/ANOAJ.2018.01.000114