JOURNAL OF COATING TECHNOLOGY AND INNOVATION
Jan-Mar 2024, VOL. 2, ISSUE 1, pp. 1-5
https://doi.org/10.61577/jcti.2024.100001

RESEAPRO JOURNALS

MINI REVIEW

Conducting polymer-based nano composites for anti corrosion coatings – a mini-review

Soumya Prakash Biswal and Swatee Acharya

[1]Department of Applied Science, Kalinga Institute of Industrial Technology University, Odisha, India
[2]Department of Chemistry, Central institute of petrochemicals engineering and technology, Bhubaneswar, India

ABSTRACT

Corrosion is a challenge in industrial places with metallic components and devices. Significant effort has been made to develop corrosion-prevention methods. Conducting polymer (CP)-based nanocomposites are promising materials for developing anticorrosion coatings. Their distinctive characteristics, such as excellent conductivity, resilience in various climatic conditions, and adaptability in creating composites, render them appealing substitutes for conventional coatings. An ideal high-performance anticorrosion CP nanocomposite should possess excellent electrical and thermomechanical characteristics, little water absorption, biocompatibility, and exceptional UV and chemical stability. CP-based nanocomposites have been discovered to effectively inhibit corrosion in aerospace and aviation structural elements, electronic components, and biomedical devices. This brief review discusses the CP-based nanocomposites as they have excellent properties. Moreover, the methods and performance of anticorrosion coatings are explained. Nevertheless, there are a multitude of obstacles that must be overcome in this field to develop nanocomposites that are more resistant to corrosion. The current challenges of metal corrosion can be resolved by replacing metal-based materials with advanced nanomaterials in future research on polymer nanocomposites.

KEYWORDS

Conducting polymer; Nanocomposites; CP coatings; Anticorrosion; CPC

ARTICLE HISTORY

Received 22 February 2024; Revised 21 March 2024; Accepted 28 March 2024

Introduction

Conducting polymers (CPs), a class of organic materials with conjugated electronic structures is gaining interest in electrochemical sensors, metal corrosion inhibition, and more. CPs have superior electroactive, catalytic redox, and mechanical properties compared to traditional polymers. Polyaniline (PANI), polypyrrole (PPy), polythiophene, and polyindole are potential CPs with good stability, conductivity, and nontoxicity. The anticorrosive effects of CP coating on metals have been extensively studied in recent years [1].

There are limitations to traditional corrosion control methods, such as the use of metallic coatings and inhibitors, as well as their long-term efficacy and environmental impact. The CP composites (CPC) and nanocomposites show better properties for anticorrosion coatings [2].

Conducting polymers (CPs), a class of organic materials with conjugated electronic structures is gaining interest in electrochemical sensors, metal corrosion inhibition, and more. CPs have superior electroactive, catalytic redox, and mechanical properties compared to traditional polymers. Polyaniline (PANI), polypyrrole (PPy), polythiophene, and polyindole are potential CPs with good stability, conductivity, and nontoxicity. The anticorrosive effects of CP coating on metals have been extensively studied in recent years [1].

There are limitations to traditional corrosion control methods, such as the use of metallic coatings and inhibitors, as well as their long-term efficacy and environmental impact. The CP composites (CPC) and nanocomposites show better properties for anticorrosion coatings [2].

Besides, CPs have been evaluated as protective anticorrosion coatings in mild steel, stainless steel, iron, copper, zinc, and aluminium [3,4]. By incorporating nanoparticles into polymers, several aspects of a nanocomposite are improved, including mechanical strength, optical and electronic properties, thermal conductivity, and anticorrosion performance. Polymeric nanocomposite materials have been developed to combat corrosion and have anticorrosion, barrier, abrasion, and wear resistance properties [5].

To prevent corrosion, CPs can be doped with oxidising agents, which restrict electron flow from metal to oxidising organisms. Despite this, neat polymers have proven not to be very corrosion-resistant or wear-resistant when applied as metal coatings. To enhance the corrosion resistance of CP nanocomposites, nano-sized carbon nanoparticles (fullerene, nanodiamond, graphene, graphene oxide, carbon nanotube, carbon black, nano clay, silica, titania nanoparticles) have been incorporated into matrixes. Functionalisation enhances the performance of nanocomposites by enhancing the bonding between different components and the transmission of loads. This not only inhibits corrosion by impeding the flow of corrosive substances but also enhances the structural integrity of the nanocomposite, hence decreasing friction and improving resistance to wear [6,7].

The review paper aims to explore PANI and PPy-based composites and nanocomposites for anticorrosion coatings. It also discusses the general synthesis and properties of CPs and their nanocomposites.

*Correspondence: Dr. Soumya Prakash Biswal, Department of Applied Science, Kalinga Institute of Industrial Technology University, 751024, Odisha, India, e-mail: biswalsoumya86@gmail.com

© 2024 The Author(s). Published by Reseapro Journals. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Synthesis and Properties of CPs

The synthesis of CPs typically involves the polymerisation of monomers like aniline, pyrrole, or thiophene. Three standard methods are used for this synthesis.

a. Chemical Polymerization: This method uses oxidising agents to initiate polymerisation. It's widely used for its simplicity and scalability, although it often requires thorough purification to remove residual chemicals [1].
b. Electrochemical Polymerization: In this technique, monomers are polymerised on the surface of an electrode by applying an electrical current. This method allows for precise control over the thickness and uniformity of the polymer film, making it ideal for creating high-quality coatings.
c. Vapor-Phase Polymerization: Monomers are vaporised and then deposited on a substrate where they polymerise. This approach produces uniform, high-purity films and is particularly useful for coating complex surfaces [8].

CPs owe their conductivity to the conjugated double bonds along their backbone, which allows electrons to move freely. The level of conductivity can be significantly enhanced by introducing dopants—small molecules or ions that alter the electronic structure of the polymer. This doping process can increase conductivity by several orders of magnitude, making the polymers suitable for various electrical applications [9,10].

Cps and their mechanism in corrosion protection

CPs, including PANI and PPy, have conjugated π-electron systems that enable electron delocalisation, making them conductive. Their anticorrosion methods are generically classified as barrier protection, cathodic protection, and anode protection. As barrier protectors, these polymers provide a physical barrier that prevents corrosive chemicals from reaching the metal surface. Cathodic protection is accomplished by slowing the rate of anodic dissolution, whereas anodic protection entails the creation of a passivating oxide layer on the metal surface. CPs provide various benefits over traditional anticorrosion treatments, including a lower environmental effect and the possibility of self-healing characteristics [11,12]. However, individual CPs are unable to provide all of the properties. Consequently, composites with CP can be fabricated to provide all the properties.

CPs Composites and Nanocomposites

CP composites involve the integration of CPs into a matrix of another material, such as epoxy, polyurethane, or silicone. This combination allows the composites to utilise the inherent conductivity of the polymers to effectively combat corrosion while the matrix material adds strength and durability. The end result is a strong protective layer that not only shields metal surfaces from corrosive agents but also actively hinders the electrochemical processes that lead to corrosion [2,5].

To further enhance the coating's protective properties, nanoparticles like carbon nanotubes (CNT), graphene-based materials, or metal oxides are incorporated into the CP matrix, creating nanocomposites. These nanoparticles greatly increase the coating's surface area, conductivity, and barrier properties. For instance, polyaniline nanocomposites with graphene oxide have demonstrated exceptional performance in preventing corrosion thanks to their synergistic effects. They provide both physical barrier protection and active electrochemical inhibition [1,13].

In order to improve the characteristics of CPC and nanocomposites, the synthesis of these materials requires the use of various processes. Methods such as electrochemical polymerisation, solution casting, and in situ polymerisation are frequently utilised in the materials manufacturing process. In situ polymerisation, monomers are polymerised with fillers such as graphene, clay, or metal nanoparticles [14]. This ensures that the fillers are distributed evenly throughout the material. In order to create the composite, solution casting involves combining the polymer solution with fillers, which is then followed by the evaporation of the solvent. The CP is deposited onto a substrate via electrochemical polymerisation, which takes place in the presence of an electric field and begins with a monomer solution. The composites and nanocomposites that are produced as a result of these technologies were designed to enhance their mechanical, electrical, and anticorrosion properties [15]. The properties of CP nanocomposites for anticorrosion coatings are depicted in Figure 1.

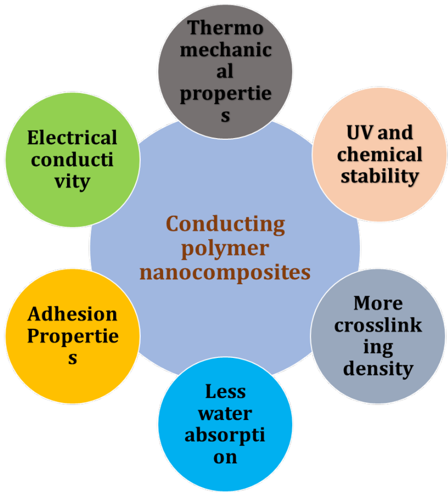

Figure 1. Re-modelling SWCNT's schematic under traverse loading on a foundation.

PANI-based composites and nano composites

These are some works related to PANI-based nanocomposites for anticorrosion coatings. Chang et al. [11] represent a comparative study of PANI/graphene and PANI/clay composites. As a result, PANI/graphene composites have better properties for anticorrosion coatings. Lin et al. [15] fabricated epoxy coatings incorporated with a composite filler of poly(styrenesulfonate)-PANI/reduced graphene oxide(rGO) by in situ oxidative polymerisation and measuring its mechanical and anticorrosion properties. Another PANI base composite, i.e., graftedepoxy@PANI, is fabricated by the Solvent casting method and reported by Zhu et al. [16] to measure the anticorrosion properties. The composite coating's surface resistance and anticorrosion performance indicate that the favourable wet adherence of the graftedepoxy@PANI coating contributes to its anticorrosion properties. Situ et al. [12] analysed the anticorrosion properties of epoxy-PANI/Titanium nitride (TiN) composites and concluded that these composites are effective for steel surfaces. Numerous other studies have fabricated composites of epoxy and PANI for anticorrosion coatings, consistently showing that the combination of epoxy

© Reseapro Journals 2024
https://doi.org/10.61577/jcti.2024.100001

RESEAPRO JOURNALS

and PANI improves the protective properties of the coatings [17-19]. These composites generally exhibit enhanced adhesion, electrical conductivity, and mechanical strength, all of which contribute to their superior performance in preventing corrosion.

PPy-based composites and nanocomposites

Ioniță et al. studied the anticorrosion and mechanical properties of PPy/functionalised SWCNT nanocomposites [20]. Jiang et al. compared two composites, PPy/GO and PPy/camphor sulfonic acid, and revealed that PPY-GO promotes adhesion, whereas PPY-CSA increases the coating's conductivity. Another Scientist, Liu et al., represents the conductivity and anticorrosion properties of electrodeposited graphene/polypyrrole composites fabricated through one-step electropolymerisation [21]. Compared to polypyrrole coating, this composite coating has superior conductivity and greater chemical stability. Lu et al, fabricated PPy@functionalized boron nitride nanosheets for superior anticorrosion coatings [14]. As a result, this composite coating outperformed pure epoxy by 58 times, with a corrosion rate of only 15 nm per year. The addition of metal nanoparticles to PPy, including zinc and titanium dioxide, enhances its anticorrosion capabilities [22,23]. These nanoparticles improve the composite's mechanical strength and increase its protection against corrosion by adding more active sites for the process.

Although the results are positive, there are numerous constraints associated with nanocomposites and composites based on CPs. The homogenous dispersion of additives(fillers) within the Polymer matrix is a primary challenge that is essential for achieving optimal performance. Furthermore, further research is required to investigate the long-term stability and durability of these composites in severe environmental conditions. Additionally, the scalability and practical application of these materials are restricted by the complexity and expense of the synthesis process.

Methods and Performance Evaluation of CPC Coatings

The general anticorrosion coating methods for CPC include electrochemical polymerisation, chemical vapour deposition (CVD) and dip-coating. Good adhesion and uniformity are ensured by electrochemical polymerisation via electrochemical oxidation, which deposits a polymer onto a metal substrate. CVD is the process by which a high-purity, high-performance coating is achieved by depositing a polymer layer from a vapour phase. Dip-coating refers to immersing the substrate into a polymer solution and then pulling it out, leaving behind a thin and uniform film. Every technique has its unique advantages regarding coating quality, uniformity and compatibility of the substrates used [24-26]. Various important things must be considered while evaluating and assessing the performance of these coatings. The first is their electrical conductivity, which is critical for use in electronics and sensor technology. CP coatings may be modified to have high conductivity by doping them with different chemicals. For example, when doped with particular acids, PANI exhibits dramatically increased conductivity, making it excellent for use in lightweight, flexible batteries and sensors [27].

Corrosion resistance is another important performance parameter. CP coatings operate as a protective barrier, keeping corrosive ions from accessing the metal surface [28]. PANI and PPy coatings are very useful in this area. They generate a passive oxide layer on the metal surface, acting as a corrosion barrier. This feature is useful in areas where metal constructions are subjected to extreme weather conditions, such as marine and automotive applications [29].

Mechanical qualities such as adhesion, flexibility, and toughness are critical to the longevity of CP coatings. These coatings must stick to the substrate and sustain mechanical forces without breaking or flaking. Advances in nanocomposite technology have greatly enhanced these qualities. Researchers created coatings with high mechanical strength and flexibility by integrating nanoparticles such as graphene, carbon nanotubes, and metal oxides into the polymer matrix. These modifications increase the coatings' resistance to mechanical wear and tear, increasing their lifespan efficiency [29,30].

Environmental stability is another important consideration when assessing the performance of CP coatings. These coatings must retain their qualities under a variety of environmental circumstances, including moisture, UV radiation, and temperature variations. Recent studies have concentrated on increasing the environmental resilience of these coatings. For example, moisture-resistant and UV-stable CP coatings have been created, with promising results in terms of long-term performance [31]. In addition to these characteristics, the simplicity of application and cost-effectiveness of CP coatings are critical factors in their commercial viability. Electrochemical deposition, spin coating, and spray coating are popular methods for applying these coatings. These technologies provide consistent coating thickness and scalability, making them appropriate for large-scale industrial applications [32].

Testing the performance of CP coatings commonly employs a variety of methodologies. Electrical conductivity may be tested using four-point probe methods, whereas corrosion resistance is frequently assessed using electrochemical impedance spectroscopy (EIS) and salt spray testing. Tensile and flexural tests are used to evaluate mechanical qualities, whereas accelerated ageing experiments under controlled settings are used to determine environmental stability [33,34].

Conclusions and Future prospectives

CPC and its nanocomposites create a barrier that prevents metals like steel, aluminium, copper, etc, from being exposed to harmful elements in corrosive environments. These compounds enhance the durability of metals by providing both physical shielding and electrochemical protection. The lifespan and performance of these structures and devices are extended and improved by exploiting their excellent adhesion, conductivity, and corrosion resistance. Applications of anticorrosion coatings include infrastructure, marine vessels, automotive parts, and electronics. Such coatings make use of the conjugated π-electron systems of these CPs, allowing them to be excellent barriers against corrosive agents, with very good electric conductivity and mechanical strength.

Despite these developments, some issues remain. The homogeneous dispersion of nanoparticles in the polymer matrix is essential to ensure optimal performance. Long-term stability and durability of such composites under harsh environmental conditions also remain to be further ascertained.

© Reseapro Journals 2024

https://doi.org/10.61577/jcti.2024.100001

The complexity and cost of the synthesis process are also bottlenecks to large-scale commercial application.

Future research challenges would include developing more synthesis methods that could bring about efficiency and scalability in the process and exploring new nanoparticle-polymer combinations that can further boost performance. Other interesting lines of inquiry might include the development of self-healing CP coatings able to autonomously repair damage and extend their lifetime. With the continuous development of the field, CP coatings provides huge opportunities for exploitation in next-generation protective coatings that offer significantly enhanced performance with less environmental impact and lower cost.

Disclosure statement

No potential conflict of interest was reported by the author.

References

1. Peng T, Xiao R, Rong Z, Liu H, Hu Q, Wang S, et al. Polymer nanocomposite-based coatings for corrosion protection. Chem Asian J. 2020;15(23):3915-3941. https://doi.org/10.1002/asia.202000943
2. Rangel-Olivares FR, Arce-Estrada EM, Cabrera-Sierra R. Synthesis and characterization of polyaniline-based polymer nanocomposites as anti-corrosion coatings. Coatings. 2021;11(6):653. https://doi.org/10.3390/coatings11060653
3. Cai K, Zuo S, Luo S, Yao C, Liu W, Ma J, et al. Preparation of polyaniline/graphene composites with excellent anti-corrosion properties and their application in waterborne polyurethane anticorrosive coatings. RSC advances. 2016;6(98):95965-95972. https://doi.org/10.1039/C6RA19618G
4. Cai M, Yan H, Li Y, Li W, Li H, Fan X, et al. Ti3C2Tx/PANI composites with tunable conductivity towards anticorrosion application. J Chem Eng. 2021;410:128310. https://doi.org/10.1016/j.cej.2020.128310
5. Kausar A. Corrosion prevention prospects of polymeric nanocomposites: A review. J plast film sheet. 2019;35(2):181-202. https://doi.org/10.1177/8756087918806027
6. Umoren SA, Solomon MM. Protective polymeric films for industrial substrates: A critical review on past and recent applications with conducting polymers and polymer composites/nanocomposites. Prog Mater Sci. 2019;104:380-450. https://doi.org/10.1016/j.pmatsci.2019.04.002
7. Yang C, Wei H, Guan L, Guo J, Wang Y, Yan X, et al. Polymer nanocomposites for energy storage, energy saving, and anticorrosion. J Mater Chem. 2015;3(29):14929-14941. https://doi.org/10.1039/C5TA02707A
8. Jang J. Conducting polymer nanomaterials and their applications. Emissive materials nanomaterials. 2006:189-260. https://doi.org/10.1007/12_075
9. Yi N, Abidian MR. Conducting polymers and their biomedical applications. InBiosynthetic polymers for medical applications Woodhead Publishing. 2016;(243-276). https://doi.org/10.1016/B978-1-78242-105-4.00010-9
10. Iqbal S, Ahmad S. Recent development in hybrid conducting polymers: synthesis, applications and prospects. J Ind Eng Chem. 2018;(60):53-84. https://doi.org/10.1016/j.jiec.2017.09.038
11. Chang CH, Huang TC, Peng CW, Yeh TC, Lu HI, Hung WI, et al. Novel anticorrosion coatings prepared from polyaniline/graphene composites. Carbon. 2012;50(14):5044-5051. https://doi.org/10.1016/j.carbon.2012.06.043
12. Situ Y, Ji W, Liu C, Xu J, Huang H. Synergistic effect of homogeneously dispersed PANI-TiN nanocomposites towards long-term anticorrosive performance of epoxy coatings. Prog Org. Coat. 2019;130:158-167. https://doi.org/10.1016/j.porgcoat.2019.01.034
13. Hu C, Kwan K, Xie X, Zhou C, Ren K. Superhydrophobic polyaniline/TiO2 composite coating with enhanced anticorrosion function. React Funct Polym. 2022;179:105381. https://doi.org/10.1016/j.reactfunctpolym.2022.105381
14. Lu F, Liu C, Chen Z, Veerabagu U, Chen Z, Liu M, et al. Polypyrrole-functionalized boron nitride nanosheets for high-performance anti-corrosion composite coating. Surf Coat Tech. 2021;420:127273. https://doi.org/10.1016/j.surfcoat.2021.127273
15. Lin YT, Don TM, Wong CJ, Meng FC, Lin YJ, Lee SY, et al. Improvement of mechanical properties and anticorrosion performance of epoxy coatings by the introduction of polyaniline/graphene composite. Surf Coat Tech. 2019;374:1128-1138. https://doi.org/10.1016/j.surfcoat.2018.01.050
16. Zhu A, Wang H, Sun S, Zhang C. The synthesis and antistatic, anticorrosive properties of polyaniline composite coating. Prog Org Coat. 2018;122:270-279. https://doi.org/10.1016/j.porgcoat.2018.06.004
17. Zhu X, Ni Z, Dong L, Yang Z, Cheng L, Zhou X, et al. In-situ modulation of interactions between polyaniline and graphene oxide films to develop waterborne epoxy anticorrosion coatings. Prog Org Coat. 2019;133:106-116. https://doi.org/10.1016/j.porgcoat.2019.04.016
18. Li C, Xu J, Xu Q, Xue G, Yu H, Wang X, et al. Synthesis of Ti3C2 MXene@ PANI composites for excellent anticorrosion performance of waterborne epoxy coating. Prog Org Coat. 2022;165:106673. https://doi.org/10.1016/j.porgcoat.2021.106673
19. Sun M, Ma Z, Li A, Zhu G, Zhang Y. Anticorrosive performance of polyaniline/waterborne epoxy/poly (methylhydrosiloxane) composite coatings. Prog Org Coat. 2020;139:105462. https://doi.org/10.1016/j.porgcoat.2011.07.007
20. Ioniță M, Prună A. Polypyrrole/carbon nanotube composites: molecular modeling and experimental investigation as anti-corrosive coating. Prog Org Coat. 2011;72(4):647-652. https://doi.org/10.1016/j.porgcoat.2011.07.007
21. Liu S, Pan TJ, Wang RF, Yue Y, Shen J. Anti-corrosion and conductivity of the electrodeposited graphene/polypyrrole composite coating for metallic bipolar plates. Prog Org Coat. 2019;136:105237. https://doi.org/10.1016/j.porgcoat.2019.105237
22. Chen Z, Yang W, Xu B, Chen Y, Qian M, Su X, et al. Corrosion protection of carbon steels by electrochemically synthesized V-TiO2/polypyrrole composite coatings in 0.1 M HCl solution.J. Alloys Compd. 2019;771:857-868. https://doi.org/10.1016/j.jallcom.2018.09.003
23. Zhu Q, Li E, Liu X, Song W, Zhao M, Zi L, et.al. Synergistic effect of polypyrrole functionalized graphene oxide and zinc phosphate for enhanced anticorrosion performance of epoxy coatings. Composites Part A: Appl Sci Manuf. 2020;130:105752. https://doi.org/10.1016/j.compositesa.2019.105752
24. Ates M. A review on conducting polymer coatings for corrosion protection. J Adhes. Sci Technol. 2016;30(14):1510-1536. https://doi.org/10.1080/01694243.2016.1150662
25. Pan T, Yu Q. Long-term anti-corrosion performance of a conducting polymer-based coating system for steels. J Mater Eng Perform. 2016;25:2384-2394. https://doi.org/10.1007/s11665-016-2118-0
26. Kausar A. Polymer coating technology for high performance applications: Fundamentals and advances. J Macromol Sci Part A. 2018;55(5):440-448. https://doi.org/10.1080/10601325.2018.1453266
27. Teijido R, Ruiz-Rubio L, Echaide AG, Vilas-Vilela JL, Lanceros-Mendez S, Zhang Q. State of the art and current trends on layered inorganic-polymer nanocomposite coatings for anticorrosion and multi-functional applications. Prog Org Coat. 2022;163:106684. https://doi.org/10.1016/j.porgcoat.2021.106684
28. Xu H, Zhang Y. A review on conducting polymers and nanopolymer composite coatings for steel corrosion protection. Coatings. 2019;9(12):807. https://doi.org/10.3390/coatings9120807

© Reseapro Journals 2024
https://doi.org/10.61577/jcti.2024.100001

29. Deshpande PP, Jadhav NG, Gelling VJ, Sazou D. Conducting polymers for corrosion protection: a review. J Coat Technol Res. 2014;11:473-494. https://doi.org/10.1007/s11998-014-9586-7
30. Nawaz M, Yusuf N, Habib S, Shakoor RA, Ubaid F, Ahmad Z, et al. Development and properties of polymeric nanocomposite coatings. Polymers. 2019;11(5):852. https://doi.org/10.3390/polym11050852
31. Fazli-Shokouhi S, Nasirpouri F, Khatamian M. Polyaniline-modified graphene oxide nanocomposites in epoxy coatings for enhancing the anticorrosion and antifouling properties. J Coat Technol Res. 2019;16:983-997. https://doi.org/10.1007/s11998-018-00173-3
32. Aly KI, Younis O, Mahross MH, Tsutsumi O, Mohamed MG, Sayed MM. Novel conducting polymeric nanocomposites embedded with nanoclay: synthesis, photoluminescence, and corrosion protection performance. Polym J. 2019;51(1):77-90. https://doi.org/10.1038/s41428-018-0119-6
33. Kausar A, Ahmad I, Eisa MH, Maaza M. Avant-garde polymer/graphene nanocomposites for corrosion protection: design, features, and performance. Corros Mater Degrad. 2023;4(1):33-53. https://doi.org/10.3390/cmd4010004
34. Sun Y, Li C, Fu D, Hu H, Bai Z, Geng H, et al. A novel high anti-corrosion performance polymer based composite coating with new functional fillers. Prog Org Coat. 2022;162:106603. https://doi.org/10.1016/j.porgcoat.2021.106603

© Reseapro Journals 2024
https://doi.org/10.61577/jcti.2024.100001