

## FORMULATION-DRIVEN OPTIMIZATION OF ALKYD / EPOXY-ESTER PRIMER-ENAMEL SYSTEMS FOR ENHANCED ANTICORROSION PERFORMANCE OF STEEL SUBSTRATES

© S.L. Zharov<sup>1</sup>, O.V. Kvasov<sup>2</sup>

National Technical University “Kharkiv Polytechnic Institute”, 61002, Kharkiv, 2 Kirpichova St., Ukraine

<sup>1</sup> Zharov Serhii L., Postgraduate Student of the Department of Oil, Gas and Solid Fuel Processing Technologies (TPNG and TP), ORCID: 0009-0007-0038-2802, e-mail: [slzharov1977@gmail.com](mailto:slzharov1977@gmail.com)

<sup>2</sup> Kvasov Oleksandr V., Postgraduate Student of the TPNG and TP, ORCID: 0009-0000-2948-692X, e-mail: [0099778@gmail.com](mailto:0099778@gmail.com)

Alkyd and epoxy-ester primer-enamel systems continue to be popular as industrial corrosion protection of steel structures because they are technologically versatile, cost-effective, and can be used with familiar application equipment. Nevertheless, their anticorrosion properties are directly linked pigment loading, interfacial modification, and inhibitor functionality. The current research reports a logical experimental study on formulation-guided performance enhancement in the application of an alkyd/epoxy-ester-based primer-enamel coating over carbon steel surfaces. Eight standard coatings were prepared under the same technological conditions, differing in zinc phosphate concentration, the addition of organic corrosion inhibitors, and the application of silane-based adhesive promoters. Quality indicators, including dry-film thickness, adhesion (ISO 2409), defect density, and inhibitor efficacy, were assessed before exposure to corrosive conditions. The quantitative damage metrics of time to first visible corrosion, corroded surface area, delamination length, and adhesion retention were used to evaluate the post-exposure corrosion behavior. A relative corrosion resistance index was used to plot performance trends that are dependent on formulation. The findings indicate that formulation optimization results in significant, numerically measurable improvements in anticorrosion performance. Enhanced zinc phosphate loading also led to increased film build and barrier integrity with silane adhesive promoters, resulting in higher interfacial stability and underfilm corrosion resistance. The optimized formulation showed a 2× delay in corrosion initiation compared to the baseline system, accompanied by a significant decrease in corroded surface area and delamination length. The results validate that, in alkyd/epoxy-ester systems, synergistic interactions that form a barrier, stabilize interfaces, and provide active inhibition result in effective anticorrosion protection. The results provide a technical formulation design for an industrial-level primer-enamel coating intended for use in a corrosion-resistant service environment.

This study is also relevant to the coke-chemical industry, where anticorrosion coating systems are widely applied to protect steel equipment used in coal processing, coking plants, and associated technological units operating in aggressive chemical environments.

Keywords alkyd coatings; epoxy-ester systems; anticorrosion primers; zinc phosphate pigment; silane adhesion promoters; organic corrosion inhibitors; coating formulation optimization.

Corresponding author S.L. Zharov, e-mail: [slzharov1977@gmail.com](mailto:slzharov1977@gmail.com)

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## References

1. Yan A., Xiao Y., Ren H., Lin B., Zhang H., Wang Y., Li X., Wang B., Tang J., (2025). Combining the life cycle model and corrosion model to analyze the impact of corrosion on carbon emissions of steel pipelines. *Environmental Impact Assessment Review*, 115, 108027. <https://doi.org/10.1016/j.eiar.2025.108027>.
2. Amaechi B., McGarrell B., Luong M., Okoye L., Gakunga P., (2021). Prevention of white spot lesions around orthodontic brackets using organoselenium-containing antimicrobial enamel surface sealant. *Heliyon*, 7(3), e06490. <https://doi.org/10.1016/j.heliyon.2021.e06490>.
3. Das P., Devi N., (2025). Alkyd resins from Argemone mexicana seed oil: synthesis and characterization for use in anticorrosive coating applications. *International Journal of Polymer Analysis and Characterization*, 30(7), 815-833. <https://doi.org/10.1080/1023666X.2025.2504559>.
4. Zhang Y., Chen T., Tong S., Zhou Y., Zhang Z., Chen J., Liu Q., Wang B., Chen F., (2026). NH<sub>4</sub><sup>+</sup>-doped flower-like zinc phosphate-reinforced waterborne epoxy coatings: structural characterization and corrosion protection. *Applied Surface Science*, 720(A), 165229. <https://doi.org/10.1016/j.apsusc.2025.165229>.
5. Han S., Ke C., Wu Y., Yu B., Wang X., Wang L., Li D., Zhou F., Liu J., (2026). Bifunctional inhibitors of benzotriazole-loaded Ce-MOFs advanced anti-corrosion of epoxy coating. *Progress in Organic Coatings*, 213, 109952. <https://doi.org/10.1016/j.porgcoat.2026.109952>.
6. Trembecka-Wójciga K., Ortyl J., (2024). Enhancing 3D printed ceramic components: The function of dispersants, adhesion promoters, and surface-active agents in Photopolymerization-based additive manufacturing. *Advances in Colloid and Interface Science*, 332, 103251. <https://doi.org/10.1016/j.cis.2024.103251>.
7. Alamiery A., Shaker L., (2026). Smart and green corrosion inhibitors: Mechanisms, computational tools, and sustainable protection strategies. *Materials Chemistry and Physics*, 348(2), 131639. <https://doi.org/10.1016/j.matchemphys.2025.131639>.
8. Li X., Zhou S., (2024). The anticorrosion behavior and mechanism of Ti<sub>3</sub>C<sub>2</sub> nanosheets for titania pigmented epoxy coatings. *Progress in Organic Coatings*, 197, 108822. <https://doi.org/10.1016/j.porgcoat.2024.108822>.
9. Barsana A., Nasar S., Umapathy M., (2025). Enhanced corrosion resistance of zinc phosphate coatings on mild steel through incorporation of nanocrystalline CeO<sub>2</sub> and CeO<sub>2</sub>-CuO nanocomposite††Electronic supplementary information (ESI) available. *RSC Advances*, 15(26), 20916-20934. <https://doi.org/10.1039/d5ra02800k>.
10. Safir E., Ettahiri W., Boutaqqa O., Lazrak J., Naamane S., Rais Z., Wiedmer S., Adardour M., Taleb M., (2026). Synthesis, characterization, and mechanistic insight into benzimidazole-based organic inhibitors for mild steel corrosion protection in acidic media. *Journal of Molecular Structure*, 1356, 145156. <https://doi.org/10.1016/j.molstruc.2025.145156>.
11. Pham V., Nguyen N., Pham K., Thai T., Pham T., Pham L., Vu O., Nguyen D., Tran L., Nguyen H., Le V., (2024). One pot synthesis of amino silane grafted cerium phosphate (AS@CePO<sub>4</sub>) as an effective anticorrosion nanopigment for epoxy coating. *Progress in Organic Coatings*, 192, 108480. <https://doi.org/10.1016/j.porgcoat.2024.108480>.
12. Xiong G., Kang P., Zhang J., Li B., Yang J., Chen G., Zhou Z., Li Q., (2019). Improved adhesion, heat resistance, anticorrosion properties of epoxy resins/POSS/methyl phenyl silicone coatings. *Progress in Organic Coatings*, 135, 454-464. <https://doi.org/10.1016/j.porgcoat.2019.06.017>.
13. Huang X., Liu R., Li T., Li J., Wu H., Chen Y., Zhang Y., Yin Y., (2026). Integrated antifouling and anticorrosion fluorine-containing epoxidized soybean oil-based waterborne polyurethane coatings. *Progress in Organic Coatings*, 212, 109881. <https://doi.org/10.1016/j.porgcoat.2025.109881>.
14. Yang S., Zhang Y., Zou Q., Jiang X., Jiang S., (2025). Non-destructive quantification of corrosion under coatings and evaluation of coating performance using terahertz time-domain spectroscopy. *Construction and Building Materials*, 501, 144251. <https://doi.org/10.1016/j.conbuildmat.2025.144251>.
15. Hidalgo-Araujo A., Salomão R., Berardi U., Dornelles K., (2025). Design and characterization of a SiO<sub>2</sub>-TiO<sub>2</sub> coating containing organic and inorganic thermochromic pigments and optimized with TiO<sub>2</sub>-P25 for improved long-term performance in energy-efficient roofing. *Solar Energy Materials and Solar Cells*, 289, 113655. <https://doi.org/10.1016/j.solmat.2025.113655>.
16. Zhou H., Deng W., Wang Q., Liang R., Wang D., (2025). Synergetic effect of passivity and hydrophobicity on the anticorrosion of magnesium phosphate cement-based coating on mild steel in Portland cement paste. *Construction and Building Materials*, 492, 143007. <https://doi.org/10.1016/j.conbuildmat.2025.143007>.
17. Negi P., Chandra V., Kumar A., Kumar P., Priya, Yashmin K., Kumar N., Joshi N., Saxena R., Kumar A., Dhiman N., Rawat B., (2025). Plant-mediated synthesis of metal oxide nanocomposites: emerging prospects in electrochemical corrosion inhibition and biosensing. *Sustainable Chemistry for Climate Action*, 7, 100107. <https://doi.org/10.1016/j.scca.2025.100107>.
18. Tan Y., (2013). An overview of techniques for characterizing inhomogeneities in organic surface films and underfilm localized corrosion. *Progress in Organic Coatings*, 76(5), 791-803. <https://doi.org/10.1016/j.porgcoat.2013.02.001>.
19. Papavasileiou E., Rekkas D., Dallas P., Pispas S., Pippa N., (2026). Unlocking the potential of micelles: DoE and QbD strategies for formulation development and optimization. *Journal of Drug Delivery Science and Technology*, 115(2), 107795. <https://doi.org/10.1016/j.jddst.2025.107795>.
20. Miroshnichenko D.V., Desna N.A., Kaftan Y.S. (2014). Oxidation of coal in industrial conditions. 2. Modification of the plastic and viscous properties on oxidation. *Coke and Chemistry*. 57, P.375-380. <https://doi.org/10.3103/S1068364X14100056>.

21. Miroshnichenko D. V., Drozdnyk Y. D., Kaftan Yu. S., Desna N. A., Holovko M. B. (2015). Oxidation of Pokrovskoe coal in laboratory and natural conditions. 1. Kinetics of oxidation and technological properties. *Coke and Chemistry*, 58, P. 79-87. <https://doi.org/10.3103/S1068364X15030059>.
22. Miroshnichenko D. V., Drozdnyk Y. D., Kaftan Yu. S., Desna N. A., Holovko M. B. (2015). Oxidation of Pokrovskoe coal in laboratory and natural conditions. 2. Expansion pressure. *Coke and Chemistry*, 10, P. 392-400. <https://doi.org/10.3103/S1068364X15100051>.
23. Miroshnichenko D. V., Drozdnyk Y. D., Kaftan Yu. S., Desna N. A. (2014). Assessment of the oxidation of coking coal. *Coke and Chemistry*, 5, P.153-162. <https://doi.org/10.3103/S1068364X14050068>.
24. Miroshnichenko D. V., Desna N. A., Drozdnyk Y. D. (2012). Influence of the oxidation of coal on the yield of coking products in the laboratory. *Coke and Chemistry*, 5, P. 167-176. <https://doi.org/10.3103/S1068364X12050067>.
25. Miroshnichenko D. V., Desna N. A. (2019). Petrographic Assessment of the Oxidation of Coking Coal. *Coke and Chemistry*, 4, P. 131-140. <https://doi.org/10.3103/S1068364X19040057>.
26. Miroshnichenko D. V., Desna N. A. (2019). Features of chemical composition and technological properties of oxidized coals. *International Journal of Coal Science & Technology*. 5 (4). P. 445–454. <https://doi.org/10.1007/s40789-018-0228-z>.
27. Miroshnichenko D. V., Desna N. A. (2024). Prediction of Volatile Matter Yield from Coals and Coal Blends. *Chemistry & Chemical Technology*. 18 (2). P 232–242. <https://doi.org/10.23939/chcht18.02.232>.
28. Miroshnichenko D. V., Desna N. A. (2023). Prediction of Coal Blends Properties Based on Their Genetic and Technological Characteristics. *Chemistry & Chemical Technology*. 17 (2). P. 357-369 <https://doi.org/10.23939/chcht17.02.357>.
29. Miroshnichenko D. V. (2011). Relationship between the volatile matter and the chemical composition of coal. *Coke and Chemistry*. 5, P.151-159. <https://doi.org/10.3103/S1068364X11050036>.