**Misan Journal of Engineering Sciences** ISSN-E: 2957-4250
Vol. 4, No. 2, Dec 2025 ISSN: 2957-4242

# ENHANCING THE ENVIRONMENTAL CONDITIONS IN EDIFCES AND CONSTRUCTIONS BY THE APPLICATION OF BIO-RESISTANT COATINGS

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*(Received 13 July, Revised 15 Aug, Accepted 19 Aug)*

**Abstract:** Microscopic organisms pose a significant threat to various structural materials such as wood, metal, and reinforced concrete. Their proliferation contributes to the emergence of technogenic mycoses, mycotoxicoses, and microallergoses, which negatively affect human health and environmental quality. This study aims to develop optimized formulations of protective coatings with enhanced bio-resistance for application in building structures. Using epoxy binders, fungicidal additives, finely dispersed fillers, and a range of pigments, we designed and tested thick-layer coatings. A mathematical experimental design was employed to identify optimal component proportions. The coatings were evaluated for fungal resistance using standard techniques (GOST 9.049-91). Results revealed that all samples exhibited varying levels of microbial contamination, leading to reductions in strength and elasticity. However, the incorporation of biocidal agents, particularly copper sulfate, significantly improved the biological stability of the coatings. These findings support the application of biocidal-enhanced coatings to prolong structural durability and promote healthier built environments.

**Keywords** Bio-resistant coatings, Epoxy composites, Fungal resistance, Building materials, Environmental durability, Fungicidal additives, Sanitary engineering, Indoor air quality, Microbial degradation, Sustainable construction

## 1. Introduction

Reinforced concrete, metal, and wood structures are frequently exposed to biologically active environments throughout their service life. Biological corrosion has become an increasingly significant factor affecting the structural integrity and reliability of buildings. Globally, over 50% of construction and industrial materials are susceptible to microbial degradation due to the integration of biotechnological processes in various production sectors.

The colonization of structures by microscopic fungi not only accelerates material deterioration but also poses serious risks to human health, including technogenic mycoses, mycotoxicoses, and mycoallergoses. These organisms thrive in both industrial and residential settings, deteriorating indoor environmental quality and structural performance.

DOI: https://doi.org/10.61263/mjes.v4i2.189

One of the most effective strategies for protecting construction materials from microbial attack is the application of bio-resistant paint and varnish (P&V) coatings. These coatings form a protective film that offers specific mechanical and physicochemical properties while inhibiting microbial growth. However, conventional P&V coatings are prone to biodegradation over time, leading to surface discoloration, cracking, and performance loss..

The biodegradation process is primarily driven by mold fungi of various genera (Aspergillus, Penicillium, Trichoderma, etc.), which metabolize coating components or surface contaminants. To improve resistance, the formulation of coatings must be tailored to include effective film-forming agents, stabilizers, plasticizers, solvents, pigments, and suitable biocidal additives.

This research addresses the urgent need for bio-resistant coatings by developing and analyzing advanced epoxy-based formulations enhanced with fungicidal compounds and fine fillers. These coatings aim to improve both the mechanical durability and biological stability of materials used in modern construction.

From an environmental and public health perspective, the biological degradation of construction materials contributes to the deterioration of indoor air quality and increases the risk of mycotoxin exposure in built environments. Therefore, the development of bio-resistant coatings not only extends the service life of structures but also enhances the hygienic conditions of residential, medical, and industrial buildings. This aligns with the objectives of environmental and sanitary engineering, particularly in promoting healthier built environments through sustainable material design.

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## 2. Research Aim

The aim of this study is to develop and optimize epoxy-based protective coatings that demonstrate improved mechanical performance and enhanced resistance to microbial degradation for application in construction materials and structures.

## 3. Research Objectives

1. To evaluate the physical, mechanical, and biological resistance properties of various coating formulations based on epoxy resins.
2. To apply a mathematical experimental design approach for optimizing the compositions of coatings, varying the type and quantity of pigments, solvents, plasticizers, and hardeners.
3. To investigate the effects of different fillers and biocidal additives on the fungal resistance and mechanical behavior of the coatings.
4. To identify formulations that balance high performance with effective antifungal properties, suitable for implementation in real-world construction applications.

## 4 Material and methods

In the experimental experiments, ED-16 epoxy resin functioned as the binder, polyethene polyamine as the hardener, acetone as the solvent, and dibutyl phthalate as the plasticiser. Low-deficit achromatic and chromatic pigments, extensively utilised in producing paints and varnishes of many hues, were employed for colouration. Zinc white, aluminium powder, and carbon black (white and black soot) were utilised among the achromatic pigments, yielding white and silver-grey and white and black hues, respectively. Two kinds of pigments of the second type were utilised: yellow, orange, red, and green, blue, violet. A shared characteristic of the pigments in the first group is their capacity to absorb light in the short-wave region of the visible spectrum, resulting in colours referred to as "warm". The second group is distinguished by its capacity to absorb electromagnetic radiation in the long-wave region of the visible spectrum, producing colours referred to as "cold". The utilised colour pigments included iron minium (red), dark cobalt violet, light ochre (yellow), iron azure (dark blue), iron oxide yellow, glauconite green, and lead crown (yellow).

Material tests for fungus resistance and fungicidal qualities were conducted by GOST 9.049 - 91 using prism samples of 1 x 1 x 3 cm. The subsequent varieties of micromycetes were employed as test organisms: Aspergillus oryzae Cohn; Aspergillus niger van Tieghem; Aspergillus terreus Thom; Chaetomium globosum Kunze; Paecilomyces variety Bainier; Penicillium funiculus Thom; Penicillium chrysogenum Thom; Penicillium cyclopean Westling; Trichoderma viride P. C. ex Fr. The tests aimed to maintain mould-spore-contaminated materials under optimal conditions for growth, thereafter evaluating fungal resistance and fungicidal efficacy. Fungal overgrowth and the corresponding alterations in strength and rigidity were regarded as criteria for evaluating the microbiological resistance of materials. Overgrowth was assessed by analysing samples with the Czapek-Dox nutritional medium (method 3) and without supplementary carbon and mineral nutrients (method 1). Mathematical techniques for experimental design were employed to formulate compositions using pigments. A second-order Latin cube was selected as the planning matrix, representing a complete factorial experiment 33, partitioned into nine blocks of three experiments each [26,27]. The variable elements included the composition of the hardener, solvent, plasticiser, and pigment type. The component contents were adjusted to -1, 0, and +1 levels. The quantities of each component, expressed in parts by weight relative to 100 parts by weight of epoxy resin, were as follows: polyethene polyamine - 8, 10, and 12; acetone - 0, 5, and 10; dibutyl phthalate - 0, 5, and 10. The pigment type for each experiment was selected based on the planning matrix, where they are represented by distinct symbols: A - iron red lead; B - dark cobalt violet; C - bright ocher; D - iron azure; E - iron oxide yellow; F - glauconite green; G - aluminium powder; H - white lead; I - lead crown.

Highly dispersed silicate powders, predominantly used in the paint and varnish sector, were employed as talc, kaolin, and technical carbon fillers.

## 5 Results

During operation, paints and varnishes endure mechanical effects from external loads, shrinkage, temperature deformations, and various physical and chemical-biological processes. In this context, material fouling was investigated by assessing alterations in the strength and elastic modulus of composites following exposure to biological environments. Samples maintained in a biological environment per method 3 underwent physical and mechanical testing. Table 1 presents the planning matrix and the experimental outcomes.

The study results indicate that the concentrations of hardener, solvent, and plasticiser, along with the pigment type employed, significantly influence the biostability of materials. The fouling of materials assessed by method 1 fluctuates between 2 and 4 points. The static analysis of the results facilitated the identification of fungus-resistant compositions exhibiting varying viscosities and elevated dry residue content. Table 2 presents the formulations of paints and varnishes exhibiting antifungal characteristic

**Table 1** Planning matrix and experimental results

| Experience No. | Planning matrix | | | | Degree of mushroom growth, points | | Characteristics of fungus resistance according to GOST 9.049-91 | Relative change in indicators after testing by method 3 | |
|---|---|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | Method 1 | Method 3 | | strength | rigidity |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | -1 | -1 | -1 | A | 3 | 4 | non-fungus resistant | 0,913 | 0,736 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2 | -1 | 0 | -1 | E | 3 | 5 | non-fungus resistant | 0,857 | 0,860 |
| 3 | -1 | +1 | -1 | I | 3 | 4 | non-fungus resistant | 0,796 | 1,043 |
| 4 | 0 | -1 | -1 | B | 3 | 4 | non-fungus resistant | 0,891 | 1,024 |
| 5 | 0 | 0 | -1 | F | 4 | 4 | non-fungus resistant | 0,885 | 0,931 |
| 6 | 0 | +1 | -1 | G | 3 | 4 | non-fungus resistant | 0,884 | 0,899 |
| 7 | +1 | -1 | -1 | C | 3 | 5 | non-fungus resistant | 0,925 | 1,288 |
| 8 | +1 | 0 | -1 | D | 3 | 5 | non-fungus resistant | 0,835 | 0,627 |
| 9 | +1 | +1 | -1 | H | 2 | 5 | fungus resistant | 0,877 | 1,054 |
| 10 | -1 | -1 | 0 | D | 3 | 5 | non-fungus resistant | 0,922 | 0,810 |
| 11 | -1 | 0 | 0 | H | 3 | 5 | non-fungus resistant | 0,974 | 0,993 |
| 12 | -1 | +1 | 0 | C | 3 | 5 | non-fungus resistant | 0,876 | 0,809 |
| 13 | 0 | -1 | 0 | E | 2 | 4 | fungus resistant | 0,930 | 1,236 |
| 14 | 0 | 0 | 0 | I | 3 | 5 | non-fungus resistant | 0,855 | 0,921 |
| 15 | 0 | +1 | 0 | A | 3 | 5 | non-fungus resistant | 0,882 | 0,870 |
| 16 | +1 | -1 | 0 | F | 3 | 4 | non-fungus resistant | 0,883 | 0,866 |
| 17 | +1 | 0 | 0 | G | 4 | 5 | non-fungus resistant | 0,903 | 0,766 |
| 18 | +1 | +1 | 0 | B | 3 | 5 | non-fungus resistant | 0,878 | 1,007 |
| 19 | -1 | -1 | +1 | G | 2 | 5 | fungus resistant | 0,855 | 1,112 |
| 20 | -1 | 0 | +1 | B | 2 | 4 | fungus resistant | 0,939 | 0,880 |
| 21 | -1 | +1 | +1 | F | 2 | 3 | fungus resistant | 0,927 | 0,792 |
| 22 | 0 | -1 | +1 | H | 2 | 4 | fungus resistant | 0,852 | 0,585 |
| 23 | 0 | 0 | +1 | C | 3 | 5 | non-fungus resistant | 0,876 | 0,618 |
| 24 | 0 | +1 | +1 | D | 2 | 4 | fungus resistant | 0,861 | 1,155 |
| 25 | +1 | -1 | +1 | I | 2 | 5 | fungus resistant | 0,827 | 1,108 |
| 26 | +1 | 0 | +1 | A | 3 | 5 | non-fungus resistant | 0,880 | 1,009 |
| 27 | +1 | +1 | +1 | E | 3 | 5 | non-fungus resistant | 0,928 | 1,240 |

**Table 2** Fungus-resistant paints and varnishes

| Pigment type | Content of components per 100 parts by weight of binder | | | |
|---|---|---|---|---|
| | PEPA | Acetone | Dibutyl Phthalate | Pigment |
| 1 | 2 | 3 | 4 | 5 |
| Zinc oxide | 12 | 10 | – | 2,5 |
| | 10 | – | 10 | 2,5 |
| Iron oxide yellow | 10 | – | 5 | 1,8 |
| Aluminum powder | 8 | – | 10 | 2,0 |
| Cobalt violet | 8 | 5 | 10 | 2,0 |
| Glauconite green | 8 | 10 | 10 | 2,3 |
| Iron blue | 10 | 10 | 10 | 1,2 |
| Lead crown | 12 | – | 12 | 2,0 |

The investigations indicated that none of the examined compositions possess fungicidal characteristics, as evidenced by a fouling score of 4-5 points when evaluated using method 3. The introduction of supplementary carbon and mineral nutrients alters the strength and elastic modulus of the paint and varnish components. All evaluated compositions exhibited a reduction in strength; the deformability of the material varied based on the concentrations of the hardener, solvent, plasticiser, and the kind of pigment used in the composition. To safeguard building structures subjected to severe liquid hostile conditions or potential impact and abrasive elements, thick-layer paint and varnish coatings are employed, utilising both low- and high-filled compositions. A filler is a crucial aspect of these formulations, in addition to a binder that dictates the physical and mechanical characteristics and longevity. We utilised extensively distributed silicate powders as fillers, specifically talc, kaolin, and carbon black. Literature indicates that talc enhances the structural viscosity of paints, improves the weather resilience of coatings, and increases resistance to abrasion and scratching. At the same time, kaolin is characterised by its excellent wetting properties. Carbon black possesses numerous advantageous properties, including exceptional chemical resistance and resistance to light and heat. It absorbs light across the visible spectrum and in the infrared and ultraviolet ranges.

Furthermore, it can form chain complexes, facilitating the creation of compositions with superior electrical properties. This enables the utilisation of carbon black in weather-resistant, antistatic, and several other coatings. The quantitative proportions of fillers were established for low- and highly filled compositions, respectively (in parts by weight): 0.8 and 25 (white carbon black); 5 and 92 (black carbon black); 30 and 80 (talc); 15 and 95 (kaolin) per 100 parts by weight of the resin. Table 3 presents the findings of the compositions tested for fungal resistance.

**Table 3** Test results

| Type of compositions | Type of filler | Bending strength, MPa | Compressive strength, MPa | Fungus resistance, points |
|---|---|---|---|---|
| Low filling | No superfluous content | 35,0 | 88,0 | 3 |
| | Silica | 34,4 | 43,4 | 5 |
| | Carbon black | 32,0 | 80,2 | 4 |
| | Kaolin | 32,2 | 86,8 | 4 |
| | Talc | 35,4 | 72,3 | 4 |
| Highly filled | No superfluous content | 35,0 | 88,0 | 3 |
| | Silica | 27,3 | 66,0 | 4 |
| | Carbon black | 37,6 | 87,1 | 4 |
| | Kaolin | 34,8 | 70,9 | 4 |
| | Talc | 37,4 | 50,0 | 4 |

The analysis of the results indicates that compositions containing carbon black, kaolin, and talc powders lack antifungal characteristics, meaning they can serve as a nutrient source for mould fungi. Incorporating these additives into fungal-resistant paint and varnish formulations will evidently diminish their biological resistance.

Now, both domestic and international researchers have devised numerous techniques to enhance the biological resistance of industrial and construction materials, among which the incorporation of biocidal additives, specifically fungicides, is one of the most efficient and enduring.

A multitude of additives have been suggested to safeguard composite materials from fouling. They inhibit the growth and development of microorganisms with varied degrees of intensity. Fungicides utilised to protect paint and varnish materials comprise substances from several types of chemical compounds: inorganic, organometallic, and organic [25,28].

We evaluated thiourea and copper sulphate as fungicidal additives, included in amounts of 2.5, 5, and 10 parts by weight per 100 parts by weight of epoxy resin. Iron red lead, ochre, and black carbon functioned as pigments for paint and varnish, while kaolin, talc, and white carbon acted as fillers. Table 4 presents the paint, varnish, and filled composition test results.

**Table 4** Examination of fungal resistance and fungicidal characteristics of paints and varnishes containing fungicidal additives

| Type of pigment or filler | Type of additive | Amount of additive, wt. | Degree of fouling, points | | Characteristics of fungus resistance according to GOST 9.049-91 |
|---|---|---|---|---|---|
| | | | Method 1 | Method 3 | |
| **1** | **2** | **3** | **4** | **5** | **6** |
| Iron red lead | thiourea | - | 3 | 5 | Non-fungus resistant |
| | | 2,5 | 1 | 4 | Resistant to fungi |
| | | 5,0 | 1 | 4 | Resistant to fungi |
| | | 10,0 | 1 | 4 | Resistant to fungi |
| | copper sulfate | - | 3 | 5 | Non-fungus resistant |
| | | 2,5 | 2 | 4 | Resistant to fungi |
| | | 5,0 | 2 | fungicidal zone– 30 мм | Fungicidal |
| | | 10,0 | 0 | fungicidal zone – 30 мм | Fungicidal |
| Ocher | thiourea | - | 3 | 5 | Non-fungus resistant |
| | | 2,5 | 1 | 4 | Resistant to fungi |
| | | 5,0 | 1 | 4 | Resistant to fungi |
| | | 10,0 | 1 | 4 | Resistant to fungi |
| | copper sulfate | - | 3 | 5 | Non-fungus resistant |
| | | 2,5 | 0 | fungicidal zone – 8 mm | Fungicidal |
| | | 5,0 | 0 | fungicidal zone – 10 mm | Fungicidal |
| | | 10,0 | 0 | fungicidal zone – 10 mm | Fungicidal |
| Kaolin | thiourea | - | 4 | 5 | Non-fungus resistant |
| | | 2,5 | 1 | 4 | Resistant to fungi |
| | | 5,0 | 1 | 3 | Resistant to fungi |
| | | 10,0 | 0 | 3 | Resistant to fungi |
| | copper sulfate | - | 4 | 5 | Non-fungus resistant |
| | | 2,5 | 1 | 4 | Resistant to fungi |
| | | 5,0 | 1 | 3 | Resistant to fungi |
| | | 10,0 | 0 | 0 | Fungicidal |
| Talc | thiourea | - | 4 | 5 | Non-fungus resistant |
| | | 2,5 | 1 | 4 | Resistant to fungi |
| | | 5,0 | 1 | 4 | Resistant to fungi |
| | | 10,0 | 0 | 4 | Resistant to fungi |
| | copper sulfate | - | 4 | 5 | Non-fungus resistant |
| | | 2,5 | 0 | 4 | Resistant to fungi |
| | | 5,0 | 0 | 4 | Resistant to fungi |
| | | 10,0 | 0 | 4 | Resistant to fungi |
| Carbon black | thiourea | - | 4 | 5 | Non-fungus resistant |

| | | | | | |
|---|---|---|---|---|---|
| | | 2,5 | 0 | 4 | Resistant to fungi |
| | | 5,0 | 0 | 4 | Resistant to fungi |
| | | 10,0 | 0 | 4 | Resistant to fungi |
| | copper sulfate | - | 4 | 5 | Non-fungus resistant |
| | | 2,5 | 2 | 4 | Resistant to fungi |
| | | 5,0 | 2 | 4 | Resistant to fungi |
| | | 10,0 | 0 | fungicidal zone – 15 mm | Fungicidal |
| Silica | thiourea | - | 4 | 5 | Non-fungus resistant |
| | | 2,5 | 2 | 4 | Resistant to fungi |
| | | 5,0 | 2 | 4 | Resistant to fungi |
| | | 10,0 | 0 | 3 | Resistant to fungi |
| | copper sulfate | - | 4 | 5 | Non-fungus resistant |
| | | 2,5 | 1 | 4 | Resistant to fungi |
| | | 5,0 | 1 | 4 | Resistant to fungi |
| | | 10,0 | 0 | 3 | Resistant to fungi |

The studies indicate that among the additives evaluated, copper sulphate demonstrates the highest efficacy, conferring fungicidal properties to materials containing iron oxide red lead, ochre, kaolin, and black carbon, as well as fungus-resistant characteristics to compositions with talc and white carbon. Thiourea enhances the fungal resistance of paint and varnish materials. The completed experiments indicate that paint and varnish materials lacking particular protection are vulnerable to biological degradation. Incorporating fungicidal chemicals advocates the enhancement of biostability in paint and varnish materials. Consumers can select the formulated material compositions to safeguard building structures against biological environmental influences.

## 6 Conclusions

This study investigated the development and evaluation of epoxy-based protective coatings designed to enhance both mechanical durability and resistance to fungal contamination in construction materials. A systematic experimental approach was used to formulate and assess coating compositions with varying pigments, fillers, solvents, plasticizers, and biocidal additives.

The findings confirmed that the type and concentration of formulation components significantly influence the bioresistance and mechanical properties of the coatings. Low- and highly-filled composites demonstrated different responses to microbial exposure, with strength and stiffness affected by both the coating matrix and environmental conditions. Coatings without fungicidal additives exhibited limited resistance, particularly under nutrient-enriched testing conditions.

Incorporating biocidal agents, particularly copper sulfate, proved to be highly effective in enhancing the biological resistance of the coatings. Formulations containing copper sulfate not only resisted fungal colonization but also demonstrated fungicidal properties under rigorous testing. Thiourea also improved resistance but to a lesser extent.

The application of these advanced bio-resistant coatings holds strong potential for extending the lifespan of building materials, especially in environments prone to high humidity or microbial contamination. The results support further exploration and scaling of these formulations for industrial use in construction and infrastructure sectors.

## 7 Limitations of the Study

While the study successfully demonstrated the enhancement of bioresistance in epoxy-based coating formulations, certain limitations should be acknowledged. Firstly, the experimental scope was limited to laboratory-scale conditions, which may not fully reflect real-world environmental complexities, such as long-term UV exposure, temperature fluctuations, or mechanical abrasion typically observed in construction environments. Secondly, the fungidal performance evaluation was limited to selected fungal strains under specific test standards (GOST 9.049 - 91), which might not encompass the diversity of microbial species encountered in different geographical zones. Additionally, although the study employed a factorial experimental design, it did not extend to advanced statistical modeling or optimization techniques such as response surface methodology (RSM) for more precise prediction of performance outcomes. Furthermore, economic feasibility and long-term environmental impacts of the fungicidal additives, especially copper sulfate, were not comprehensively assessed.

## 8 Practical Implications and Future Work

The study's findings hold significant implications for the construction and infrastructure sectors. The developed bio-resistant coatings provide a viable solution to mitigate biological degradation of building surfaces, thus extending service life, minimizing maintenance costs, and promoting healthier indoor environments. These materials can be particularly valuable in regions with high humidity, biological activity, or in sensitive applications such as hospitals, food processing units, and underground structures. Future research should aim to scale up these formulations for field applications and test their performance under varied climatic conditions. It is also recommended to explore alternative eco-friendly biocidal agents and hybrid nanocomposites to enhance both bioresistance and environmental sustainability. Additionally, lifecycle assessment (LCA) and cost-benefit analyzes should be integrated into future studies to ensure broader industrial adoption.

**Author Contributions**: The authors contributed to all parts of the current study.

**Funding**: This study received no external funding.

**Conflicts of Interest**: The authors declare no conflict of interest

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