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RESEARCH ON ANTI-CORROSION COATING TECHNOLOGIES AND COMPUTER MODELING OF CORROSION PROCESSES

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Abstract. The article discusses modern approaches to protecting building structures and materials from corrosion using polymer and silicone coatings. It is shown that the treatment of the exterior walls of buildings with silicone-containing materials provides hydrophobic properties, increases resistance to moisture and corrosion factors, while maintaining the vapor permeability of structures. Particular attention is paid to polymer materials such as polyvinyl chloride, polyethylene, and polymer compositions based on dispersion film-forming systems, which are widely used to protect metal, reinforced concrete, and building elements in aggressive environments. The paper presents mathematical models of corrosion processes, including corrosion kinetics, diffusion of aggressive substances through protective coatings, degradation of polymer materials, and electrochemical mechanisms of corrosion. Regression analysis, finite element methods, and differential equations were used to predict the durability of protective coatings. Python software has been developed using the Streamlit platform, which allows analyzing corrosion parameters, comparing materials, and evaluating the effectiveness of protective systems. The results obtained confirm the prospects of using polymer coatings and mathematical modeling to increase the reliability and durability of building and metal structures.

Keywords: corrosion, mathematical modeling, protective coatings, chemical resistance, equipment, structures.

Introduction

Water protection keeps outer walls going strong over time. Silicone applied outside handles moisture problems without trapping air inside. Even brick and plaster fronts breathe through their coating while staying dry. Polymer shields wrap buildings tightly, slowing down wear from weather exposure. Wrapped around surfaces, these shields slow wear where chemicals linger - think holding tanks, basins, or flow lines. Usually it is lightweight plastic, either PVC or polyethylene, that handles the job well [1].

One solid method to guard building parts and supplies against rust is coating them with polymers. Since those coatings do not easily break down when hit by chemicals, tanks, containers, and pipes last much longer even under tough conditions. Often, people pick bendable sheets - either from PVC or polyethylene - or go for slim plastic wraps meant just for shielding [2].

Films often come from water-driven mixes, think latex paint packed with polymer bits. You'll spot polyvinyl acetate hanging around styrene-butadiene combos, while epoxy resins tag along too.

These days, research into stopping rust involves testing various methods. Recently, fresh coatings that last longer under stress have grabbed interest. Because of their behavior in microscopic spaces, some groups study nanomaterials. When hit with tough conditions, specific metal mixes reveal unique reactions - this draws separate investigations. At the same time, progress moves ahead on substances fixing minor harm without help. Something moves ahead when surfaces change to cut down on chemical activity. Not every route needs old methods, each one holds different chances [3].

1) Nanotechnology:

When nanomaterials get added, anti-corrosion coatings start working differently. Tiny particles help them last longer if things get rough outside. Because those small bits settle into little holes, strength goes up. Over days, they stick tighter - surfaces hold on better. Under pressure, it takes more chemical push to make them fail. Fine changes show up fast, even when the layer's barely there. A little extra does a lot, depending on what you're testing.

2) Intellectual coatings:

Once hurt, some shields start mending on their own. Tiny pods live within these substances; when cracked, they let go of repair fluids. Where breaks form, invisible currents carry helpers to the spot. Hidden parts stir only when splits appear below. A thing protects by renewing on its own. When it breaks, repair kicks in right away. Small gaps split apart when pressed. After damage comes quiet rebuilding. Strength comes back even after harm. What works fades, then shows up again later [4].

Something green in origin might just slow rust while leaving the planet unharmed. Not tied to old lab-made formulas, researchers now test what plants can offer instead. From fields rather than factories, these materials renew themselves naturally. Once finished working, they vanish into harmless pieces - no trace left behind. What matters now is shielding structures along with nearby areas using sharper chemical solutions. Signs from initial tests show they perform on par with certain standard methods. Because more people worry about contamination, businesses start looking at these options. Progress happens behind the scenes, nudging closer to lasting environmental balance - no fanfare needed [5].

3) Methods used in electrochemical studies.

With tools such as impedance scans and polarization plots, scientists spot early signs of rust alongside coating weaknesses. Instead of relying only on standard checks, a few methods follow electron movement to see if inhibitors work well. Depending on how the metal reacts, researchers switch from holding voltage steady to watching current shifts. One look might show crack patterns, another may highlight thinning layers. Results tend to change when humidity or temperature varies through experiments.

Figuring out if a coating holds up usually starts with models predicting how tough it will be, tweaking plastic components along the way. Since stuff such as polyethylene terephthalate guards metal, formulas uncover how much strain it can take before failing. Rather than sitting around for decades, researchers lean on number-based methods to build tougher anti-rust layers. Over months, these numbers back longer-lasting structures and slowly reduce costs tied to fixes. Breakthroughs may eventually lead to ultra-resilient coverings shaped by sharper chemical designs [6].

In recent years, significant attention has been focused not only on the physical properties of coatings but also on the digitalization of their analysis processes. For instance, the study by [7] reviews recent advances in environmentally sustainable polymer coatings, emphasizing the critical transition toward 'smart' materials with self-healing functionalities. Research by [8] extends the understanding of protection mechanisms by providing a comprehensive analysis of composite polymer technologies and the influence of nano-fillers on the formation of a passive layer at the metal-polymer interface. Furthermore, modern approaches to corrosion monitoring increasingly incorporate artificial intelligence and the Python programming language. For example, [9] demonstrates the effectiveness of using Python to automate the identification of corrosion damage based on microscopic images, which correlates with the application of the Streamlit platform for data visualization in current research.

Materials and research methods

Starting now, sharper ways to block rust are stretching how long products last worldwide. Science marches on, so anti-rust gear gets stronger year by year. Longer life shows up in machines once new materials take hold. Less upkeep cuts expense since shields against wear work much better. Fewer spills happen when updated tech runs things smoothly. Keeping gear in faraway spots shapes the results you see on the ground [10].

1. Corrosion Kinetics Equation: The equation describing the kinetics of corrosive processes is:

$$\frac{dC}{dt} = -kC, \quad (1)$$

where C – corrosive agents concentration,
 k – reaction speed coefficient.

2. Stress and Deformation Analysis: The Finite Element Method (FEM) is used to calculate the distribution of stress and deformation in the coating:

$$\nabla \cdot \sigma + f = 0. \quad (2)$$

3. Durability Prediction via Regression Analysis: A linear regression model can be presented in the form of the following formula to predict coating durability:

$$y = a + b_1x_1 + b_2x_2 + \dots + b_nx_n + \varepsilon, \quad (3)$$

where y – dependent variable (e.g., corrosion rate),

x_i – independent variables (e.g., coating thickness, humidity, temperature, etc.),

b_i – regression coefficients,

ε – random error term.

Fewer corrosion issues show up when different influences get weighed together through multiple regression. This method points toward the best coating settings by sorting how each factor plays a role instead of viewing them alone [11].

4. First thing, polymer layers protect metal by keeping out damaging stuff around it. To really get how that works, scientists use number-based pictures showing how things travel inside materials. What these shows is flow caused by uneven amounts spreading across the layer. Usually, they include slow seeping of water or charged particles entering the surface. 4. Time matters when corrosive stuff gets to metal. How things move ties closely to how thick the material is, also its layout. Figuring out what happens means watching how substances spread, over days that stretch on. Lasting power of shields changes because every piece plays a role in actual use [12].

One route appears when harsh invaders enter the plastic coating - oxygen, moisture, or salt particles like chlorine sneaking through weak spots. Metal damage kicks off solely once those substances touch the underlying surface. Their journey obeys an old rule named Fick's diffusion principle. That formula decides the pace and range of their spread. Movement begins where stuff is packed tight, sliding into spots with more room. How fast it goes ties to how thick the layer sits. Given enough moments, even a slow seep can build up strength. Spread unfolds in stages, each one stretching longer than the last. Differences in density push the flow – less crowded areas pull molecules in:

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}, \quad (4)$$

where $C(x, t)$ – concentration of the aggressive agent in the coating,

D – diffusion coefficient (dependent on the nature of the polymer),

x – coordinate along the coating thickness,

t – time.

5. Kinetics of Coating Degradation: Polymers degrade over time under the influence of the surrounding environment. This decay can be described by the equation:

$$\frac{dM}{dt} = -kM, \quad (5)$$

where M – the remaining whole of the coating mass,
 k – degradation speed constant (humidity, to temperature, ultraviolet to be irradiated related).

6. Electrochemical Kinetics of Corrosion Under the Coating: Corrosion proceeds according to the laws of electrochemistry, for example, via the Tafel equation:

$$i = i_0 \left(e^{\frac{\alpha n F_n}{RT}} - e^{-\frac{(1-\alpha)n F_n}{RT}} \right), \quad (6)$$

where i – corrosion current density,
 i_0 – exchange current (reaction activity describes),
 η – overvoltage at the metal-coating interface,
 α – transportation coefficient,
 n – number of electrons in the reaction,
 F – Faraday constant,
 R – universal gas constant,
 T – temperature.

7. Service Life Modeling: The service life of the protective coating t_{fail} can be estimated by solving the following approximation:

$$t_{fail} \approx \frac{L^2}{D} + \frac{1}{k}, \quad (7)$$

where L – coating thickness,
 D – diffusion of aggressive agents,
 k – rate of coating wear.

Results and discussion

Looking into rust usually means using digital models, those help design better shields against decay too. Inside such setups, what happens in fluids matters - ions drift here, neutral particles shift there, yet electric currents in metal sections keep equilibrium somehow. Testing how well coverings hold up led to a tool made via Streamlit, whose backbone comes from scripts written in Python. People sometimes label it a toolkit, but really it acts like framework bones – giving form to full programs where numbers drive choices.

A fresh start every time you open it – that's how this online platform works. Built without clutter, meant for those checking how long materials last. Folks like engineers or lab researchers use it when tracking how coatings hold up. Not everything happens at once – one piece spots changes over time. A separate section lines up results from different tests. They work alone but fit together when needed

A look at how one thing affects another drives regression analysis. Because patterns show up when numbers change together, connections appear. When values shift in a linked way, that relationship gets measured. One number moves, others follow – that link becomes clear through this method.

Over time, this tool checks how various materials resist rust. One material might weaken faster than another when exposed to moisture. Some hold up well while others show damage sooner. Tracking changes helps spot weak points early. Each test reveals differences in durability under stress.

Information goes straight into the box when typed by someone. Choosing a ready-made setup works too – see Figure 1. One way skips typing, the other builds fresh.

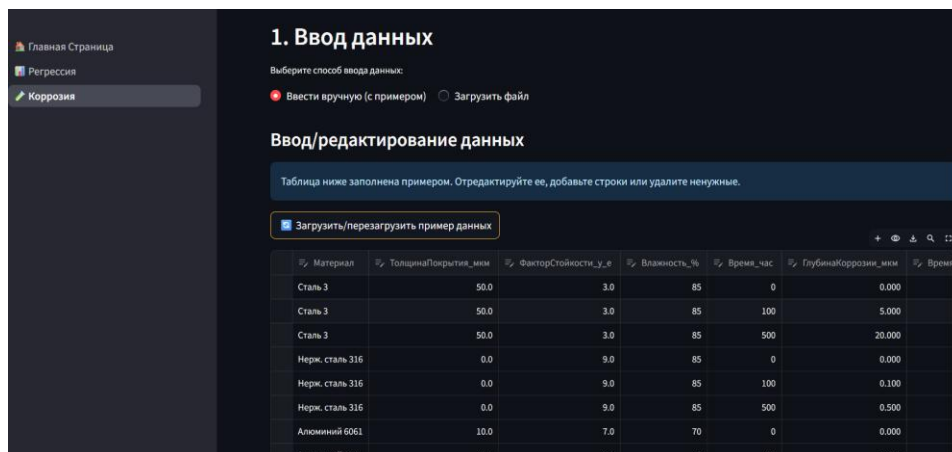


Figure 1. Data entry window

Comparison of time dependence (Figure 2):

- The software automatically detects the final moment of time (at least one numerical metric).
- It extracts main indicators for each unique material and constructs a summary table (df_comparison).
- For multiple indicators, the last known value of time is taken. For the "Starting Point Time_h," the lowest value is taken (representing the initial time of corrosion site appearance).
- This total the table shows (st.dataframe) digital values formatting and endurance Sort by indicators.

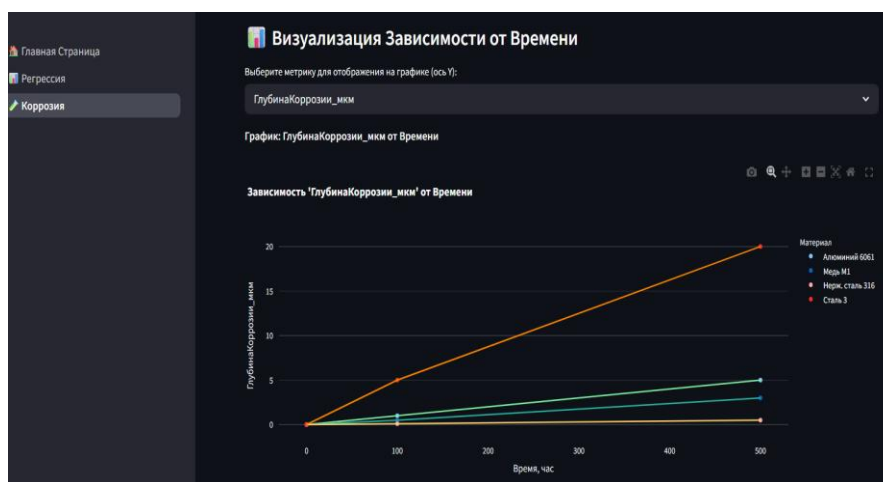


Figure 2. Comparison of time dependence

Additional comparison of corrosion resistance (Figure 3):

- A selection box allows the user to choose a specific material from the known list.
- Maps in the form of a summary table display the set of main indicators for the selected material (using st.metric) with special functions for formatting values and processing permissions. The summary table is organized into columns.
- Summary table can be downloaded (CSV and in Excel formats).

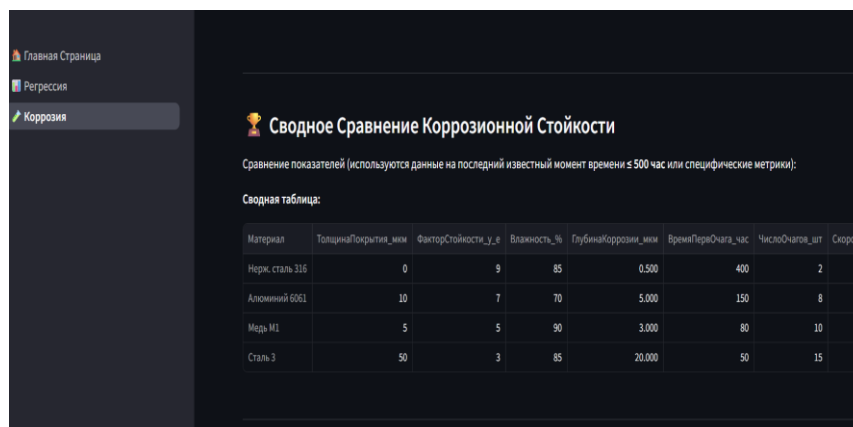


Figure 3. Additional comparison window for corrosion resistance

Conclusion

Out back, a custom-built system using Python and Streamlit manages large volumes of data about how materials corrode. This web-based platform supports specialists by offering clear insights minus clutter. Lab findings paired with mathematical simulations replace assumptions, guiding better choices in coating development. Real test results combined with digital predictions bring accuracy into sharper focus.

Furthermore, research indicates that integrating mathematical modeling with experimental data significantly enhances the reliability of evaluating the corrosion resistance of polymer protective coatings. The application of diffusion, degradation, and electrochemical kinetics models not only identifies dominant corrosion mechanisms but also enables the prediction of coating behavior under diverse operating conditions. This approach facilitates the optimization of coating thickness, polymer composition, and operational parameters during the design phase, effectively reducing the requirement for prolonged field testing.

Moreover, the developed software solution demonstrates significant potential for scalability through the integration of supplementary material databases, environmental impact scenarios, and real-time monitoring data. This provides a framework for its application in industrial diagnostics, preventive maintenance planning, and the development of intelligent corrosion-resistant coatings. The platform's adaptability makes it particularly valuable for the construction, energy, and chemical sectors, where corrosive damage entails substantial economic losses. Overall, the proposed methodology advances the development of sustainable anti-corrosion systems, extends the service life of structural components, and promotes the implementation of more robust, cost-effective, and environmentally conscious protective solutions.

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ИССЛЕДОВАНИЕ ТЕХНОЛОГИЙ ПОЛУЧЕНИЯ АНТИКОРРОЗИЙНОГО ПОКРЫТИЯ И КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССОВ КОРРОЗИИ

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Аннотация. В статье рассмотрены современные подходы к защите строительных конструкций и материалов от коррозии с применением полимерных и силиконовых покрытий. Показано, что обработка наружных стен зданий силиконсодержащими материалами обеспечивает гидрофобные свойства, повышает устойчивость к воздействию влаги и коррозионных факторов, при этом сохраняя паропроницаемость конструкций. Особое внимание уделено полимерным материалам, таким как поливинилхлорид, полиэтилен и полимерные композиции на основе дисперсионных пленкообразующих систем, широко применяемых для защиты металлических, железобетонных и строительных элементов в агрессивных средах. В работе представлены математические модели коррозионных процессов, включая кинетику коррозии, диффузию агрессивных веществ через защитные покрытия, деградацию полимерных материалов и электрохимические механизмы коррозии. Используются методы регрессионного анализа, конечных элементов и дифференциальные уравнения для прогнозирования долговечности защитных покрытий. Разработано программное обеспечение на языке Python с использованием платформы Streamlit, позволяющее проводить анализ коррозионных параметров, сравнение материалов и оценку эффективности защитных систем. Полученные результаты подтверждают перспективность применения полимерных покрытий и математического моделирования для повышения надежности и долговечности строительных и металлических конструкций.

Ключевые слова: коррозия, математическое моделирование, защитные покрытия, химическая стойкость, оборудование, конструкции.

КОРРОЗИЯҒА ҚАРСЫ ЖАБЫН АЛУДЫҢ ТЕХНОЛОГИЯЛАРЫН ЗЕРТТЕУ ЖӘНЕ КОРРОЗИЯ ПРОЦЕССТЕРІН КОМПЬЮТЕРЛІК МОДЕЛЬДЕУ

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Андатпа. Мақалада полимерлі және силиконды жабындарды қолдана отырып, Құрылыс конструкциялары мен материалдарын коррозиядан қорғаудың заманауи тәсілдері қарастырылған. Ғимараттардың сыртқы қабырғаларын силикон материалдарымен өңдеу гидрофобты қасиеттерді қамтамасыз етеді, құрылымдардың бу өткізгіштігін сақтай отырып, ылғал мен коррозия факторларының әсеріне төзімділікті арттырады. Агрессивті ортада металл, темірбетон және құрылыс элементтерін қорғау үшін кеңінен қолданылатын дисперсиялық пленка түзуші жүйелерге негізделген полимерлі материалдарға, мысалы, поливинилхлоридке, полиэтиленге және полимерлі композицияларға ерекше назар аударылады. Жұмыста коррозиялық процестердің математикалық модельдері, соның ішінде коррозия кинетикасы, қорғаныс жабындары арқылы агрессивті заттардың диффузиясы, полимерлі материалдардың деградациясы және коррозияның электрохимиялық механизмдері ұсынылған. Қорғаныс жабындарының беріктігін болжау үшін регрессиялық талдау әдістері, ақырлы элементтер және дифференциалдық теңдеулер қолданылады. Коррозиялық параметрлерді талдауға, Материалдарды салыстыруға және қорғаныс жүйелерінің тиімділігін бағалауға мүмкіндік беретін Streamlit платформасын қолдана отырып, Python тілінде бағдарламалық жасақтама жасалды. Нәтижелер Құрылыс және металл конструкцияларының сенімділігі мен беріктігін арттыру үшін полимерлі жабындар мен математикалық модельдеуді қолдану перспективасын растайды.

Түйін сөздер: коррозия, математикалық модельдеу, қорғаныс жабындары, химиялық төзімділік, жабдықтар, құрылымдар.