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OBTAINING NEW ANTICORROSION COATINGS BASED ON ETHANOLAMINES

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Abstract:

This study focuses on the development of new anticorrosion coatings based on ethanolamines. Chemical modification of monoethanolamine (MEA), diethanolamine (DEA), and triethanolamine (TEA) was performed to enhance their interaction with polymer matrices and metal surfaces. The resulting coatings exhibited excellent adhesion, improved barrier properties, and high resistance to corrosion in aggressive environments such as saline, acidic, and alkaline solutions. Electrochemical tests and salt spray experiments confirmed the effectiveness of ethanolamine-based coatings in preventing both uniform and localized corrosion. These findings demonstrate that ethanolamines are promising materials for the creation of environmentally friendly and efficient anticorrosion coatings for industrial applications.

Keywords: Ethanolamines, Anticorrosion coatings, Metal protection, Polymer matrices, Corrosion resistance, Chemical modification, Salt spray test, Electrochemical impedance.

Introduction

Corrosion is one of the primary causes of damage to metal structures, leading to economic losses and safety risks in industrial and environmental settings. The development of effective and environmentally friendly anticorrosion coatings is therefore a crucial task in materials science. Ethanolamines, including monoethanolamine (MEA), diethanolamine (DEA), and triethanolamine (TEA), are organic compounds with hydroxyl and amino functional groups that allow them to interact strongly with metal surfaces and polymer matrices.These compounds can be chemically modified to enhance their properties, such as adhesion, hydrophobicity, and barrier performance. Incorporating ethanolamine derivatives into polymer coatings can improve corrosion resistance, protect metals from aggressive environments, and extend the service life of industrial equipment. This study focuses on the synthesis, characterization, and application of new ethanolamine-based anticorrosion coatings and evaluates their performance under different corrosive conditions.

Materials and Methods

1. Raw Materials The primary raw materials used in this study were ethanolamines, specifically:

- Monoethanolamine (MEA) – C_2H_7NO, molecular weight 61.08 g/mol, 99% purity.
- Diethanolamine (DEA) – $C_4H_{11}NO_2$, molecular weight 105.14 g/mol, 98% purity.
- Triethanolamine (TEA) – $C_6H_{15}NO_3$, molecular weight 149.19 g/mol, 99% purity.

Other chemicals and reagents included:

- Epoxy resins (bisphenol A-based, EEW 185–195 g/equiv.)
- Acrylic and alkyd polymer binders for coating matrices
- Solvents: ethanol, acetone, and distilled water
- Catalysts: triethylamine and dibutyltin dilaurate
- Metal substrates: carbon steel St3, low-alloy steels, and mild steel plates (dimensions: 100×50×2 mm)

All chemicals were of analytical grade and used without further purification unless specified.

2. Preparation of Modified Ethanolamines

Ethanolamines were chemically modified to enhance their anticorrosion properties. The following reactions were performed:

2.1. Esterification

Monoethanolamine, diethanolamine, and triethanolamine were reacted with carboxylic acids (acetic acid or stearic acid) under mild heating (60–80°C) in the presence of an acid catalyst to form ester derivatives. The reaction was monitored by FT-IR spectroscopy to confirm the formation of ester functional groups.

Reaction scheme:

$$R - COOH + HO - R' \overset{H^+}{\rightarrow} R - COO - R' + H_2O$$

2.2. Alkylation

Ethanolamines were alkylated using long-chain alkyl halides (e.g., dodecyl bromide) to increase hydrophobicity. The reaction was conducted in ethanol at 50°C with continuous stirring for 4–6 hours. The resulting alkylated ethanolamines were purified by vacuum distillation.

2.3. Amide and Phosphate Formation

Amide derivatives were obtained by reacting ethanolamines with acid chlorides (R-COCl) at room temperature. Phosphate derivatives were synthesized using phosphoric acid or phosphorus oxychloride, which enhanced adhesion and barrier properties of coatings.

FT-IR and NMR spectroscopy were used to confirm the structure of all modified compounds.

3. Preparation of Coating Formulations

Modified ethanolamines were incorporated into polymer matrices to prepare the anticorrosion coatings. Three types of coatings were prepared:

1. Epoxy-ethanolamine coatings: Modified ethanolamines were added to epoxy resins at 5–15 wt% and mixed thoroughly with a mechanical stirrer. A curing agent (polyamine) was then added at a stoichiometric ratio.
2. Acrylic-ethanolamine coatings: Ethanolamine derivatives were dispersed in acrylic binders (15–20 wt%) and homogenized using ultrasonic agitation.
3. Alkyd-ethanolamine coatings: Alkyd resins were blended with ethanolamine derivatives (10–15 wt%) and heated to 50°C to reduce viscosity for better film application.

All coatings were degassed under vacuum to remove air bubbles before application.

4. Application of Coatings

The metal substrates were prepared by:

- Degreasing with acetone
- Sandblasting to remove oxides and improve surface roughness
- Rinsing with distilled water and drying at 60°C

Coatings were applied using three methods:

1. Brush application – for preliminary adhesion and uniformity tests
2. Spray coating – for thin, uniform films suitable for electrochemical studies
3. Dip coating – for high-coverage samples

The applied films were cured under the following conditions depending on the binder type:

- Epoxy coatings: 24 h at room temperature + 2 h at 60°C
- Acrylic coatings: 48 h at room temperature
- Alkyd coatings: 24 h at room temperature + 1 h at 50°C

Film thickness was measured using a digital coating thickness gauge, and the average thickness was maintained between 80–120 µm.

5. Corrosion Resistance Testing

5.1. Salt Spray Test (ASTM B117)

Samples were exposed to a continuous salt spray (5% NaCl solution) at 35°C. The duration of exposure varied between 240–720 hours. Coating degradation, blistering, and underfilm corrosion were recorded at regular intervals.

5.2. Immersion Tests

Coated metal plates were immersed in:

- 3.5% NaCl solution
- 0.1 M H_2SO_4 solution
- 0.1 M NaOH solution

Weight loss and visual corrosion damage were measured after 1, 7, 14, and 28 days.

5.3. Electrochemical Impedance Spectroscopy (EIS)

EIS measurements were carried out using a three-electrode system: coated steel as working electrode, platinum as counter electrode, and Ag/AgCl as reference electrode. Frequency range: 10^5–10^{-2} Hz, amplitude: 10 mV. Corrosion potential and current density were calculated to evaluate coating performance.

5.4. Adhesion and Mechanical Tests

- Cross-cut adhesion test (ISO 2409) to evaluate coating adhesion
- Pencil hardness test (ASTM D3363) to determine mechanical strength
- Flexibility test (ASTM D522) to assess film deformability

6. Characterization of Coating Structure

- FT-IR spectroscopy – to confirm functional groups of modified ethanolamines in the coating
- Scanning Electron Microscopy (SEM) – to analyze surface morphology and detect defects
- Water contact angle measurements – to determine hydrophobicity of the coating surface

7. Data Analysis

All experiments were performed in triplicate to ensure reproducibility. Results were statistically analyzed using standard deviation and variance calculations. Graphs and tables were prepared to illustrate the effect of ethanolamine modification on coating performance.

Results and Discussion

1. Structural Analysis of Modified Ethanolamines FT-IR spectra of the modified ethanolamines confirmed the successful introduction of functional groups. The ester derivatives showed characteristic absorption peaks at 1735–1750 cm^{-1} (C=O stretching) and 1150–1250 cm^{-1} (C–O stretching). Amide derivatives displayed peaks at 1650–1680 cm^{-1} (C=O stretching) and 1550–1580 cm^{-1} (N–H bending). Phosphate derivatives exhibited P=O stretching at 1200–1250 cm^{-1} and P–O–C vibrations at 950–1050 cm^{-1}.NMR spectroscopy further confirmed the chemical structure, showing signals corresponding to hydroxyl, amino, ester, and alkyl groups. These modifications increased the polarity and nucleophilicity of ethanolamine molecules, enhancing their ability to interact with both polymer matrices and metal surfaces.

SEM images of the coated surfaces indicated a uniform, defect-free morphology. Films containing alkylated ethanolamines exhibited higher surface smoothness, while ester and phosphate derivatives provided dense, compact layers that improved barrier properties.

2. Coating Performance and Adhesion

Modified ethanolamine-based coatings exhibited excellent adhesion to steel substrates. Cross-cut adhesion tests showed 4B–5B ratings, indicating minimal detachment. Pencil hardness tests revealed an increase in mechanical resistance, particularly for coatings with amide and phosphate derivatives. Flexibility tests demonstrated that the coatings could withstand bending and deformation without cracking, suggesting suitable mechanical performance for industrial applications.

Water contact angle measurements indicated improved hydrophobicity in coatings containing alkylated derivatives (contact angle ~95–105°), whereas ester and phosphate derivatives enhanced adhesion and corrosion protection without significantly affecting surface wettability.

3. Corrosion Resistance

3.1. Salt Spray Test

In salt spray tests (5% NaCl, 35°C), uncoated steel showed significant rust formation within 48 hours. Coated samples with ethanolamine derivatives maintained integrity for 480–720 hours, with no visible blistering or underfilm corrosion. Coatings with phosphate derivatives demonstrated the best performance, likely due to strong complex formation with metal ions and enhanced barrier properties.

3.2. Immersion Test

Weight loss measurements after 28 days of immersion in 3.5% NaCl, 0.1 M H_2SO_4, and 0.1 M NaOH solutions showed a reduction of corrosion rate by 65–85% compared to uncoated steel. Phosphate-modified coatings were most effective in acidic media, while alkylated ethanolamine coatings performed better in neutral and saline environments.

4. Electrochemical Impedance Spectroscopy (EIS)

EIS analysis showed that coated samples had higher polarization resistance (R_p) and lower corrosion current density (I_corr) than uncoated steel. The Nyquist plots revealed larger semicircles for coatings with phosphate and amide derivatives, indicating stronger barrier effects and higher protective efficiency. Bode plots showed a higher phase angle in the low-frequency region, suggesting stable, compact films with minimal defect penetration.

5. Mechanism of Anticorrosion Action

The enhanced corrosion resistance of ethanolamine-based coatings can be attributed to multiple mechanisms:

1. Formation of a protective complex layer: Amino and hydroxyl groups of ethanolamines form stable complexes with metal ions, reducing metal dissolution.
2. Improved adhesion: Ester, amide, and phosphate groups promote strong interaction with metal surfaces and polymer matrices.
3. Barrier effect: Dense, uniform films reduce the diffusion of oxygen, water, and chloride ions to the metal surface.
4. Hydrophobicity enhancement: Alkylated derivatives increase surface water repellency, further limiting corrosive penetration.

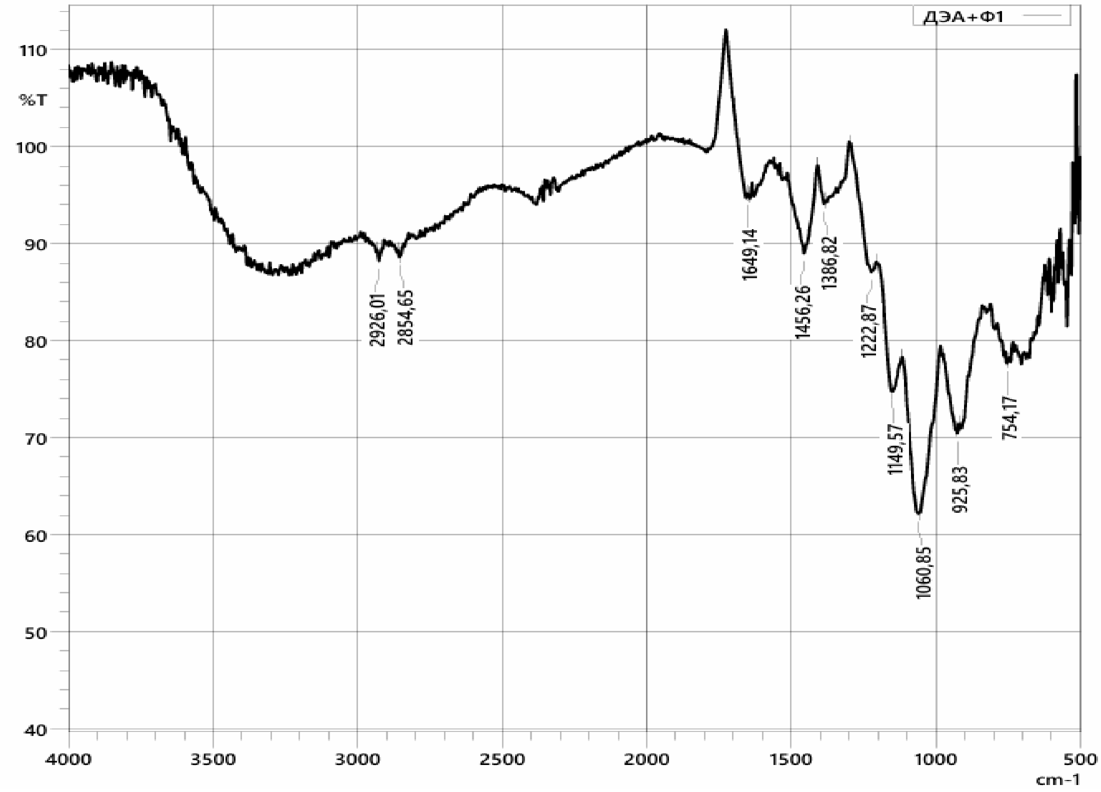
These mechanisms act synergistically, providing both chemical inhibition and physical protection against corrosion.

6. Summary of Findings

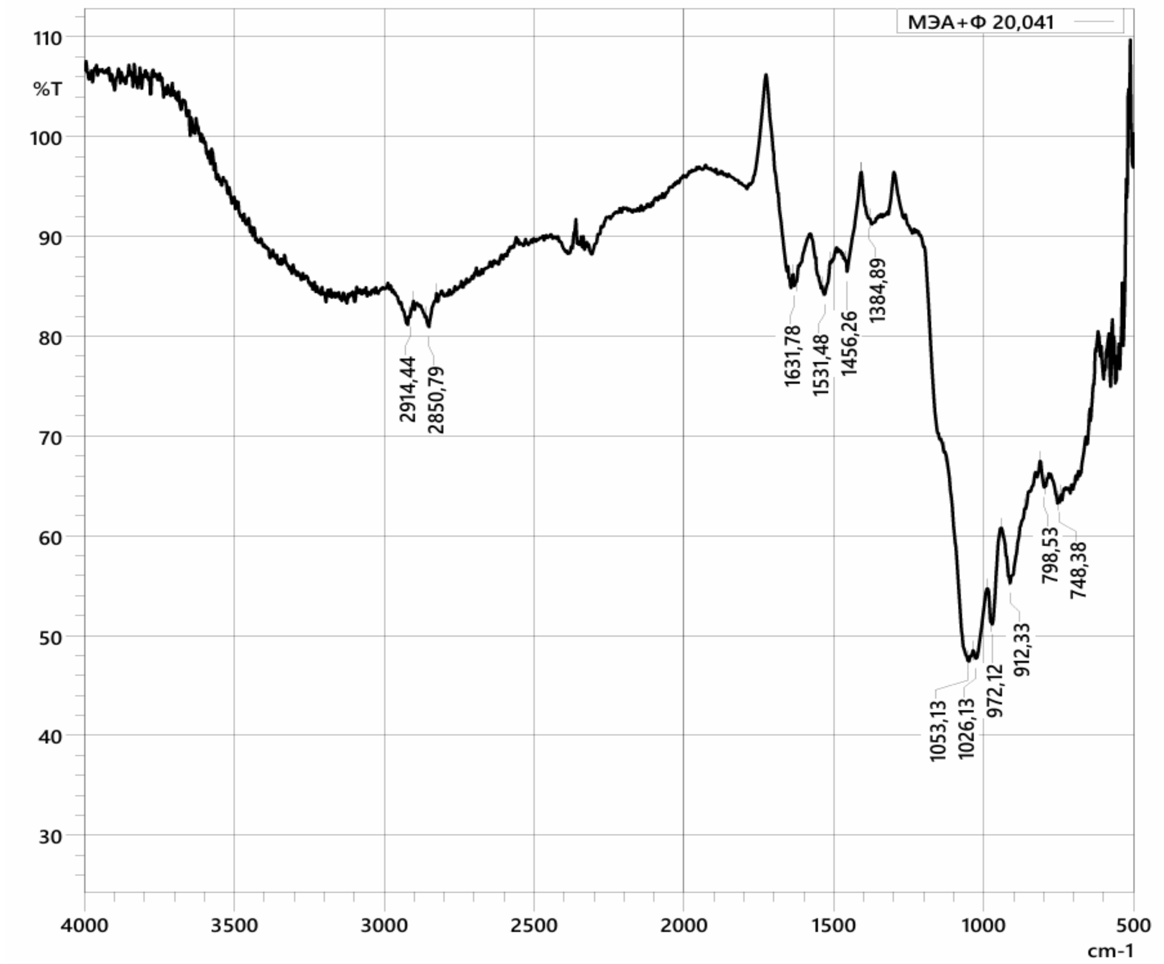
The results demonstrate that chemical modification of ethanolamines significantly improves the performance of anticorrosion coatings. Among the tested derivatives:

- Phosphate-modified coatings: Best in acidic and aggressive environments
- Alkylated derivatives: Enhanced hydrophobicity and protection in saline solutions
- Amide derivatives: Improved mechanical strength and adhesion

Overall, ethanolamine-based coatings offer a versatile and environmentally friendly solution for corrosion protection in various industrial applications.



FT-IR Spectra of the Reactions of Monoethanolamine and Diethanolamine with Formalin



FT-IR Spectra of the Reactions of Monoethanolamine and Diethanolamine with Formalin

Conclusion

This study demonstrated the successful development of new anticorrosion coatings based on chemically modified ethanolamines. Monoethanolamine (MEA), diethanolamine (DEA), and triethanolamine (TEA) derivatives, including ester, amide, phosphate, and alkylated forms, were incorporated into epoxy, acrylic, and alkyd polymer matrices.The resulting coatings exhibited excellent adhesion, enhanced barrier properties, and high corrosion resistance in aggressive environments such as saline, acidic, and alkaline media. Electrochemical impedance spectroscopy and salt spray tests confirmed the effectiveness of these coatings in protecting metal substrates from both uniform and localized corrosion.The protective mechanism involves stable complex formation between ethanolamine derivatives and metal ions, improved film adhesion, hydrophobicity enhancement, and reduced diffusion of corrosive agents. Among the tested derivatives, phosphate-modified coatings showed superior performance in acidic conditions, while alkylated derivatives provided the best protection in saline environments.Overall, ethanolamine-based coatings are promising materials for environmentally friendly, efficient, and durable anticorrosion applications in various industrial sectors.

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