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The Effect of Adding Corn Cob Inhibitor to Primer Paint as a Corrosion Retardant On Train Roofs (Mild Steel SS400)

Akbar Zulkarnain[1], Edi Nyoto Setyo Marsusiadi[1], Achmad Sholih Zidni[1], Willy Artha Wirawan[2]

[1]Department of Railway Mechanical Technology.
Indonesian Railways Polytechnic, Jl. Tirta Raya, Pojok, Nambangan Lor, Kec. Manguharjo, Madiun Regency, East Java, 63132, Indonesia.
[2]Department of Mechanical Engineering, Universitas Negeri Surabaya
Jl. Ketintang Wiyata, Ketintang, Kec. Gayungan, Surabaya, Jawa Timur 60231, Indonesia

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ABSTRACT

Corrosion is one of the main problems that can reduce the quality and service life of steel materials in the railway industry, especially on train roofs made of SS400 mild steel. This study aims to examine the effectiveness of adding natural inhibitors from corn cob ash to epoxy primer paint in inhibiting the rate of corrosion and increasing the adhesive strength of the paint. The inhibitor was made through a process of extracting silica from corn cob ash and mixing it into the primer paint at various concentrations. Fourier Transform Infra Red (FTIR) testing was used to identify the silica content in the inhibitor, while testing was carried out on the adhesive strength using an adhesion tester and the corrosion rate using the weight loss test method in HNO_3 solution. The results showed that the addition of corn cob ash inhibitor formed a protective layer on the metal surface, improved paint adhesion, and significantly reduced the corrosion rate. This study demonstrates that the use of agricultural waste such as corn cobs as a natural inhibitor is an innovative, economical, and environmentally friendly solution for controlling corrosion in steel materials in the railway industry.

Corresponding Author:

Akbar Zulkarnain
Department of Railway Mechanical Engineering, Indonesian Railway Polytechnic
Jl. Tirta Raya, Pojok, Nambangan Lor, Manguharjo, Madiun, Jawa Timur 63161, Indonesia
Email: akbar@ppi.ac.id

1. INTRODUCTION

Corrosion is a persistent and critical issue in the railway industry, particularly for rolling stock components manufactured from low-carbon mild steel such as SS400. This material is widely used for train roof structures due to its favorable mechanical properties, formability, and cost efficiency [1]. However, in tropical regions, railway vehicles operate under aggressive environmental conditions characterized by high relative humidity, elevated temperatures, intense rainfall, and prolonged wet–dry cycles. These conditions significantly accelerate electrochemical corrosion processes, leading to premature material degradation, coating delamination, and increased maintenance frequency.

In tropical railway environments, SS400 steel is continuously exposed to moisture condensation, atmospheric oxygen, acidic rainwater, and airborne pollutants originating from urban and industrial activities. Train roofs are particularly vulnerable because they experience direct exposure to rainwater accumulation, ultraviolet radiation, and temperature fluctuations during operation and outdoor parking. Such conditions promote localized corrosion, underfilm corrosion beneath coatings, and loss of coating adhesion, which ultimately compromise structural integrity and service life if not adequately controlled.

Fig. 1. Corrosion on Mild Steel Train Roofs

Epoxy-based primer coatings are commonly applied as the primary corrosion protection system for railway steel components. Nevertheless, their long-term performance strongly depends on coating adhesion and the ability to suppress corrosive reactions at the steel–coating interface [2]. Conventional synthetic corrosion inhibitors, while effective, raise concerns related to toxicity, environmental impact, and sustainability. Consequently, there is increasing interest in environmentally friendly corrosion inhibitors derived from natural and renewable resources [3].

Table 1. Mechanical Properties of Mild Steel

Mechanical Properties	Nilai
Tensile Strength (MPa)	400 – 552
Yield Strength (MPa)	281 – 301
Elongation (%)	31
Young's Modulus (GPa)	200
Poisson's Ratio	0,32
Density (kg/m3)	7800
Hardness, Brinell (HB)	119 - 159

Agricultural waste materials have emerged as promising sources of green inhibitors due to their abundance and low cost. Corncob ash, in particular, contains silica-rich compounds that can enhance coating adhesion and act as a physical barrier against the ingress of corrosive species [4,5]. Despite extensive studies on natural inhibitors in aqueous corrosion systems, research on the incorporation of silica derived from agricultural waste directly into primer coatings for railway applications—especially under tropical conditions—remains limited. Therefore, this study investigates the effectiveness of silica extracted from corncob ash as a natural corrosion inhibitor in epoxy primer coatings applied to SS400 mild steel used in train roof structures.

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2. RESEARCH METHOD

2.1 Materials

The substrate material used in this study was SS400 mild steel, which is commonly applied in railway car bodies and roof structures. The steel specimens were cut into uniform dimensions, mechanically ground using 150-grit abrasive paper, and cleaned to remove surface contaminants before coating. Commercial epoxy primer paint, along with its corresponding thinner and hardener, was used as the base coating system. Corncob waste was collected as the raw material for producing the natural corrosion inhibitor.

2.2 Preparation of Silica-Based Inhibitor

Corncob waste was first dried and subjected to controlled combustion. Initial carbonization was carried out at 200 °C for 1 h, followed by calcination at 800 °C for 4 h in a muffle furnace to obtain white corncob ash. The ash was ground, sieved to 250 mesh, and chemically extracted using a 3 M NaOH solution under heating (90–95 °C) and continuous stirring. The filtrate containing sodium silicate was allowed to age for 24 h, then titrated with 5 M H_2SO_4 until gel formation occurred at pH ≈ 2. Ammonium hydroxide was added to adjust the pH to neutral (pH 7), promoting silica precipitation. The resulting silica gel was filtered, washed with warm distilled water, dried at 100 °C, and pulverized for further use. Fourier Transform Infrared (FTIR) spectroscopy was employed to confirm the presence of silanol and siloxane functional groups in the extracted silica [4,6].

Fig 2. Final Results of Corn Cob Silica Extract

2.3 Coating Application

The extracted silica inhibitor was incorporated into the epoxy primer at different weight percentages (0%, 7%, 10%, 13%, and 15%). The 0% concentration was used as a reference to evaluate the baseline performance of the epoxy primer without inhibitor addition. The selected concentration range was designed to represent low, intermediate, and relatively high inhibitor loadings in order to systematically observe their influence on coating adhesion and corrosion resistance.

Lower concentrations (7% and 10%) were hypothesized to improve coating performance by enhancing interfacial bonding and forming an initial protective barrier without significantly altering the coating matrix. Intermediate concentration (13%) was selected based on the assumption that an optimal silica content would provide maximum adhesion enhancement and effective blockage of corrosive species diffusion. A higher concentration (15%) was included to investigate the effect of excessive inhibitor addition, which was expected to potentially reduce coating uniformity, promote particle agglomeration, and negatively affect adhesion and corrosion resistance. This approach allowed identification of the optimum inhibitor concentration for balancing adhesion strength and corrosion inhibition performance

Fig 3. Epoxy Primer Painting

2.4 Adhesion Testing

Coating adhesion strength was evaluated using the pull-off adhesion test in accordance with ASTM D4541. Aluminum dollies were bonded to the coated surface using epoxy adhesive and allowed to cure fully. A portable adhesion tester was then used to apply perpendicular tensile force until coating failure occurred. Adhesion strength was calculated as the ratio of the applied force to the dolly surface area [7].

Fig 4. Adhesion Test

2.5 Corrosion Rate Measurement

Corrosion performance was assessed using the weight loss method based on ASTM G31. Coated specimens were immersed in a corrosive HNO_3 solution for a predetermined exposure period. Although nitric acid does not directly replicate natural atmospheric exposure, it was selected as an accelerated corrosive medium to simulate aggressive conditions that may occur on train roof surfaces, such as acidic rainwater, industrial air pollutants, and localized chemical exposure during operation and outdoor parking in tropical environments [8].

In tropical railway conditions, train roofs are frequently exposed to high humidity, prolonged moisture retention, and acidic contaminants originating from urban emissions and combustion by-products. The use of an HNO_3 solution provides a controlled and repeatable environment to accelerate electrochemical reactions, allowing rapid comparative evaluation of coating performance and inhibitor effectiveness. Therefore, while the test does not aim to fully reproduce service conditions, it serves as a conservative screening method to assess the relative corrosion resistance of different inhibitor concentrations under severe exposure scenarios.

2.6 Data Analysis

All tests were conducted on multiple specimens to ensure repeatability. The effects of inhibitor concentration on coating adhesion and corrosion rate were analyzed comparatively to identify the optimum inhibitor content.

3. RESULTS AND DISCUSSION

In this study, three tests were conducted, namely FTIR (Fourier Transform Infra Red) testing, pull-off adhesion testing, and weight loss corrosion rate testing.

3.1 FTIR Results for Silica Powder

The graph below shows that the first peak value is 1053.78, followed by a peak of 776.65, and finally a peak of 693.64. The three peaks indicate silanol and siloxane functional groups, as seen in Table 2.8, number 3, where the asymmetric Si-O stretching vibration wave of (Si-OH) silanol is between 1000-1100, and number 5, where the symmetric Si-O stretching vibration wave of (Si-O -Si) siloxane is between 620-900, proving that corn cob extract does indeed contain silica.

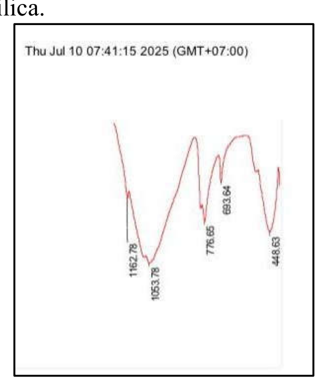

Fig 5. FTIR Graph of Silica Powder

3.2 Adhesion Test Results

The following are the average adhesion calculations using the pull-off test method.

Table 2. Average Adhesion

SPECIMEN	Average Adhesion Strength (MPa)
A (0% inhibitor)	5,72
B (7% inhibitor)	6,76
C (10% inhibitor)	7,65
D (13% inhibitor)	10,99
E (15% inhibitor)	8,56

3.3 Corrosion Rate Calculation

The following are the results of the average corrosion rate calculation using the weight loss test method.

Table 3. Average Corrosion Rate

Specimen	Average Corrosion Rate (mm/y)
A (0% inhibitor)	0,0413
B (7% inhibitor)	0,038
C (10% inhibitor)	0,0317
D (13% inhibitor)	0,0213
E (15% inhibitor)	0,0252

3.4 Discussion

3.4.1 Comparison of Adhesion Strength Values

The following is a graph of average adhesion strength.

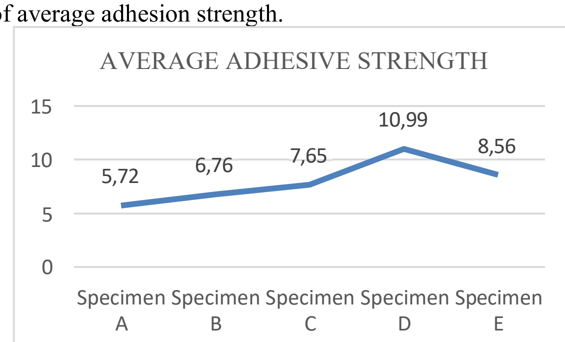

Figure 6. Average Adhesion Strength Graph

From the graph above, it can be seen that painting with the addition of 13% corn cob ash silica extract has the highest adhesion strength, with an average adhesion strength value of 10.99 MPa.

3.4.2 Comparison of Corrosion Rate Values

The following is a graph of the average corrosion rate.

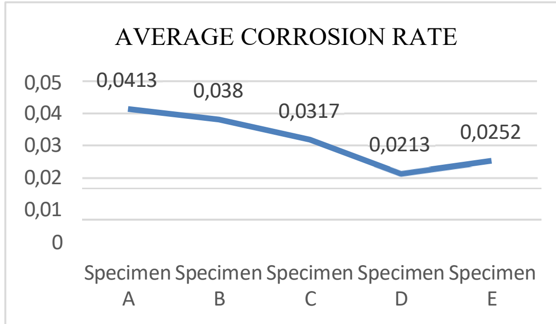

Figure 7. Average Corrosion Rate Graph

From the graph above, it can be seen that painting with the addition of 13% corn cob ash silica extract has the lowest corrosion rate, with an average corrosion rate value of 0.0213 mm/y.

The both graphical representation of adhesion strength and corrosion rate as a function of inhibitor concentration demonstrates a clear trend, with an optimum performance observed at 13% silica content. Although error bars and formal statistical tests were not applied in this study, all measurements were conducted on multiple specimens to ensure repeatability and consistency of the observed trends.

The monotonic increase in adhesion strength and the corresponding decrease in corrosion rate up to the 13% inhibitor concentration suggest a systematic effect of silica addition on coating performance. The subsequent decline in performance at 15% concentration indicates that excessive inhibitor loading may lead to particle agglomeration and reduced coating homogeneity, which is consistent with previously reported behavior in particulate-filled epoxy coatings. Future work is recommended to incorporate statistical analyses and error-bar representations to quantitatively confirm the significance of these trends under expanded experimental datasets.

4. CONCLUSION

Based on the results of the research and discussion, the following conclusions can be drawn:

1. The results of functional group identification based on FTIR testing show that corn cob inhibitors are proven to contain silica. This is indicated by the presence of an absorption peak at a wavelength of 1053.78 cm^{-1}, which shows the asymmetric Si-O stretching vibration functional group of (Si-O-Si) siloxane, and at a wavelength of 776.65 cm^{-1}, which shows the symmetric Si-O stretching vibration of (Si-O-Si) siloxane.
2. Based on the adhesion test results, specimen D with a 13% silica inhibitor concentration and a thickness of 120 µm had the highest adhesion value of 12.63 MPa. Meanwhile, the lowest adhesion strength was obtained in specimen A with a 0% silica inhibitor concentration and a thickness of 120 µm, with an adhesion strength value of 5.36 MPa. Specimen D with a 13% silica inhibitor concentration showed the highest adhesive strength, and specimen A without the addition of 0% inhibitor showed the lowest adhesive strength, but the addition of excessive inhibitors can also reduce the adhesive strength value. Thus, it can be concluded that the addition of silica inhibitors has been proven to increase the adhesive strength of the protective layer.
3. From the corrosion rate research results, it can be concluded that specimen D4 with a 13% silica inhibitor concentration and a thickness value of 120 µm is the most effective concentration in inhibiting the corrosion rate, with the smallest corrosion rate value of 0.0191 mm/y. Meanwhile, the highest corrosion rate was obtained in specimen A4 with a 0% silica inhibitor concentration and a thickness of 120 µm, which had a corrosion rate of 0.0425 mm/y. Specimen D with a 13% silica inhibitor concentration showed the lowest corrosion rate, and specimen A without 0% inhibitor addition showed the highest corrosion rate. However, excessive inhibitor addition can also increase the corrosion rate value of the concentrate below it. Thus, it can be concluded that the addition of a silica inhibitor has been proven to inhibit the corrosion rate. Specimen E with 15% inhibitor addition actually experienced an increase in corrosion rate, presumably due to overconcentration in the inhibitor composition.

The use of silica derived from agricultural waste also offers practical advantages for railway maintenance practices, as it can be integrated into existing primer application processes without significant modification to current coating systems. Although a detailed cost analysis was beyond the scope of this study, the utilization of low-cost and locally available corncob waste suggests potential economic benefits through reduced material costs and extended service intervals. Future studies are recommended to include life-cycle cost analysis and field exposure testing to quantitatively assess long-term economic and operational impacts.

REFERENCES

[1] M. G. Fontana, *Corrosion Engineering*, 3rd ed. New York, NY, USA: McGraw-Hill, 1987. [Online]. Available: https://automaterials.files.wordpress.com/2019/01/corrosion-engineering.pdf

[2] W. Funke, "Problems and progress in organic coatings science and technology," *Prog. Org. Coat.*, vol. 31, no. 1–2, pp. 5–9, 1997, doi: 10.1016/S0300-9440(97)00021-4.

[3] P. B. Raja and M. G. Sethuraman, "Natural products as corrosion inhibitor for metals in corrosive media—A review," *Mater. Lett.*, vol. 62, no. 1, pp. 113–116, 2008, doi: 10.1016/j.matlet.2007.04.079.

[4] U. Kalapathy, A. Proctor, and J. Shultz, "A simple method for production of pure silica from rice hull ash," *Bioresour. Technol.*, vol. 73, no. 3, pp. 257–262, 2000, doi: 10.1016/S0960-8524(99)00127-3.

[5] X. Zhang, H. Wang, Y. Liu, and J. Zhang, "Effect of silica particles on adhesion and corrosion resistance of epoxy coatings," *Surf. Coat. Technol.*, vol. 206, no. 7, pp. 1825–1832, 2011, doi: 10.1016/j.surfcoat.2011.07.040.

[6] R. M. Silverstein, F. X. Webster, and D. J. Kiemle, *Spectrometric Identification of Organic Compounds*, 7th ed. Hoboken, NJ, USA: Wiley, 2005.

[7] ASTM D4541-17, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*. West Conshohocken, PA, USA: ASTM International, 2017. [Online]. Available: https://www.astm.org/d4541

[8] ASTM G31-21, *Standard Guide for Laboratory Immersion Corrosion Testing of Metals*. West Conshohocken, PA, USA: ASTM International, 2021. [Online]. Available: https://www.astm.org/g0031