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Corrosion Case Study on Automobile

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OUTLINE

1. **Corrosion related to automotive coatings**

    1) Background information

    2) Mechanism

    3) Impact and corrosion control measures

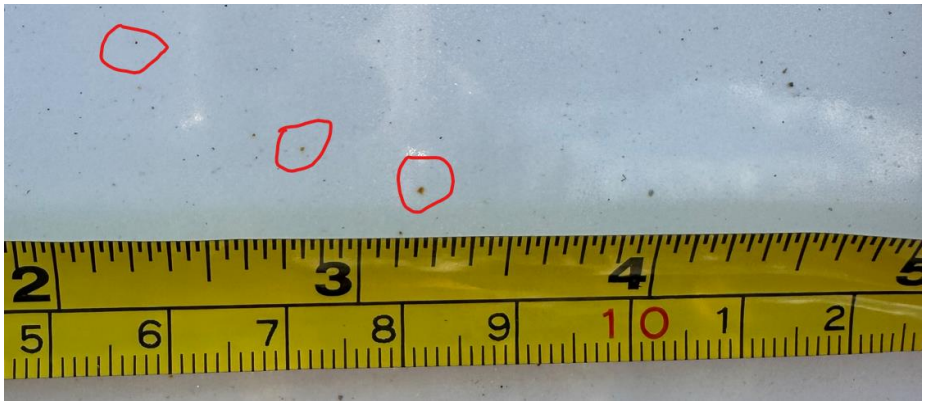
2. **Corrosion directly on metals**

    1) Introduction and definition

    2) Mechanism

    3) Case study

CORROSION RELATED TO AUTOMOTIVE COATINGS

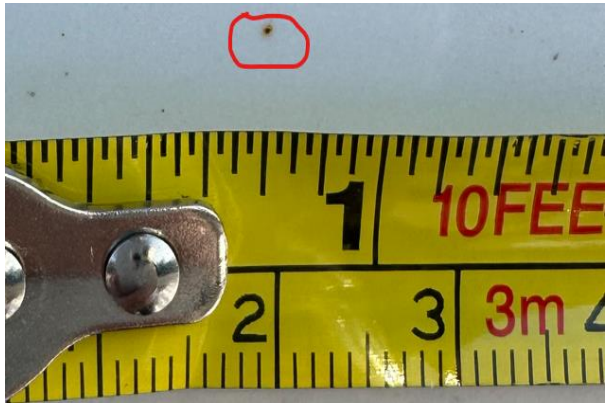


CORROSION RELATED TO AUTOMOTIVE COATINGS

Observations: rust on rear door of a minivan, coating failure, brownish colour of the substrate; not as many in the front

Causes:

- Defective coating, O_2, water, and road deicing salt containing Cl^-
- Aging/degradation of coating under sunlight, esp. UV, air pollutants NO_x, SO_x, thermal cycles, etc.
- Mechanical damage, car wash, etc.

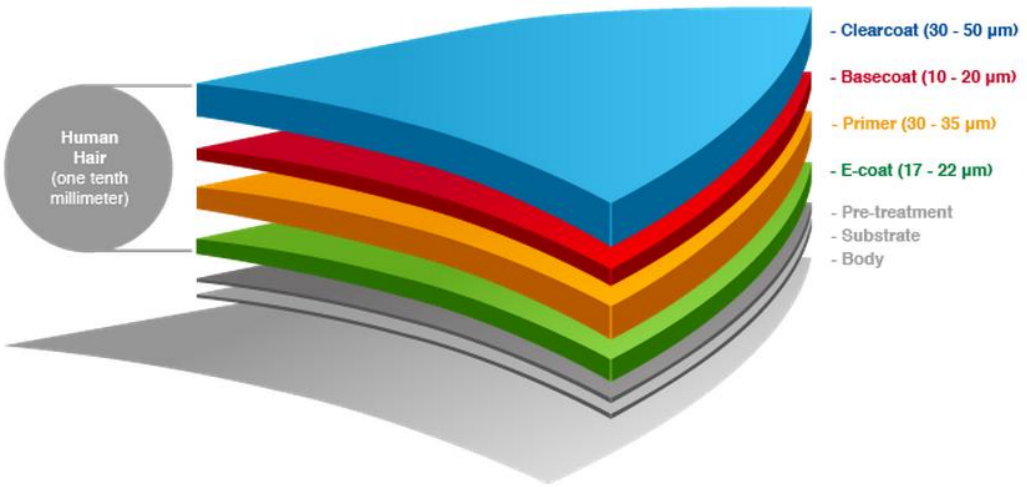


Yamamoto, N.; Ikegami, K. A Study on the Degradation of Coating and Corrosion of Ship's Hull Based on the Probabilistic Approach; 1998; Amirudin, A.; Thierry, D. PROGRESS IN ORGANIC COATINGS Application of Electrochemical Impedance Spectroscopy to Study the Degradation of Polymer-Coated Metals; ELSEVIER, 1995; Vol. 26;.

CORROSION RELATED TO AUTOMOTIVE COATINGS

Background information

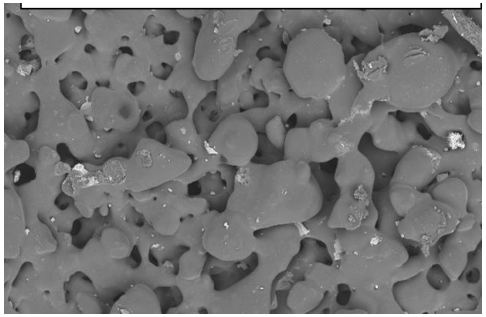
- Substrate: cold-rolled steel
- Pretreatment of steel: cleaning, phosphating, etc.
- A typical coating system for car body

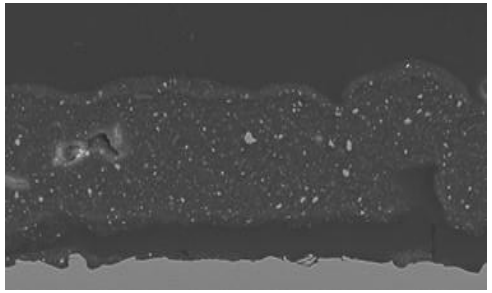


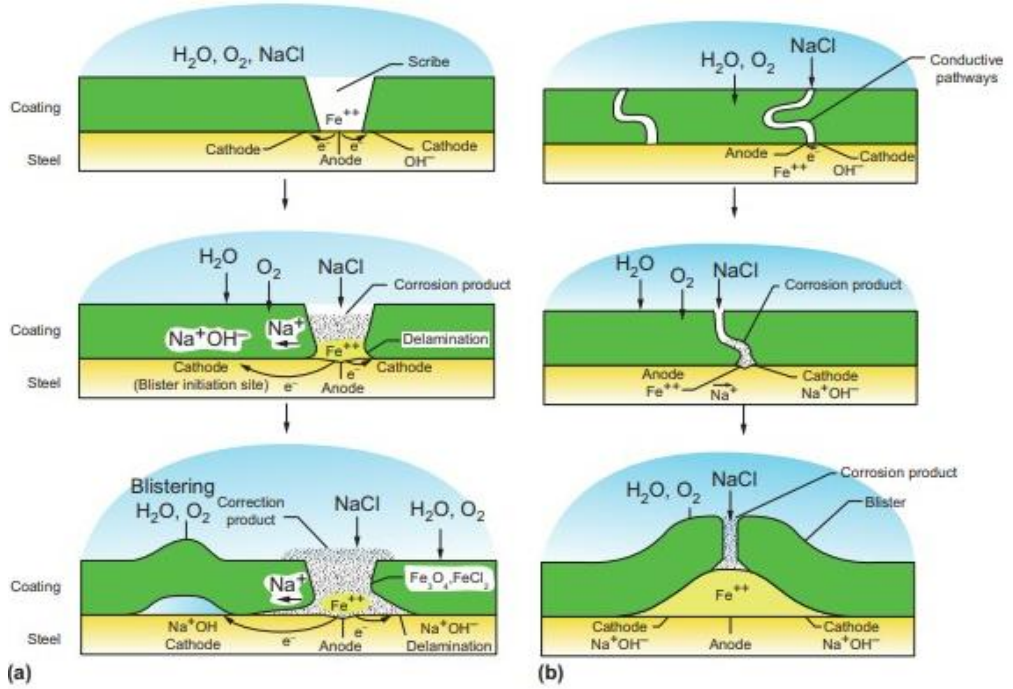
http://www.basf-coatings.com/global/ecweb/en/content/products_industries/automotive-oem-coatings/index
Sørensen, P.A.; Kiil, S.; Dam-Johansen, K.; Weinell, C.E. Anticorrosive Coatings: A Review. J Coat Technol Res 2009, 6, 135–176, doi:10.1007/s11998-008-9144-2.

MECHANISMS

- Electrolyte and oxygen ingress through pores + mechanical damage; higher pH – hydrolysis of coating binder
- Delamination of coatings
- Corrosion of substrate (Fe)







T. Nguyen, J.B. Hubbard, and J.M. Pommersheim, Unified Model for the Degradation of Organic Coatings on Steel in a Neutral Electrolyte, J. Coating. Technol., 1995

Sørensen, P.A.; Kiil, S.; Dam-Johansen, K.; Weinell, C.E. Anticorrosive Coatings: A Review. J Coat Technol Res 2009, 6, 135–176, doi:10.1007/s11998-008-9144-2.
Yang, M.S.; Huang, J.; Noël, J.J.; Chen, J.; Barker, I.; Henderson, J.D.; Zhang, H.; Zhang, H.; Zhu, J. A Mechanistic Study on the Anti-Corrosive Performance of Zinc-Rich Polyester/TGIC Powder Coatings. Processes 2022, 10, doi:10.3390/pr10091853.

MECHANISM, CORROSION OF STEEL IN CASE OF COATING FAILURE

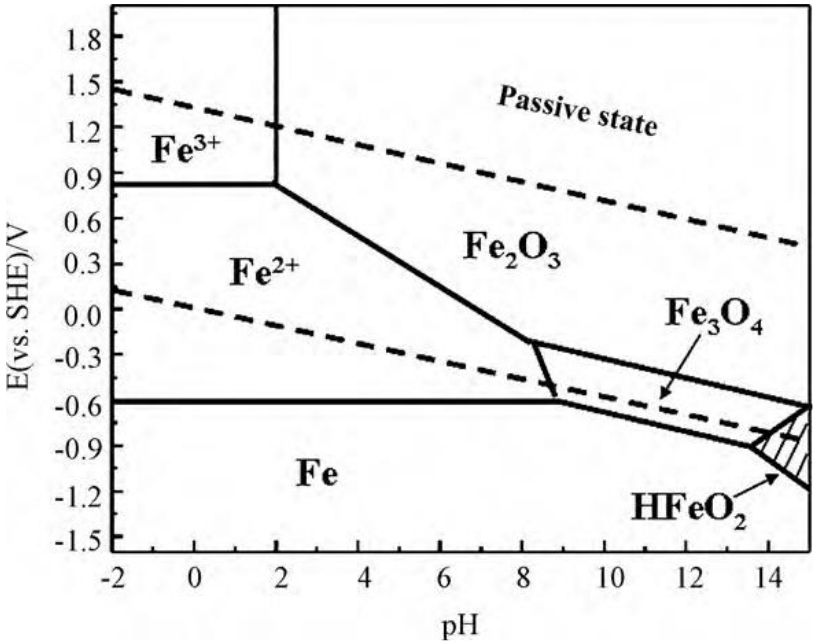


Fig. 3. E–pH diagram of Fe–H_2O system ($aFe^{2+} = 10^{-6}$).

$$Fe \rightarrow Fe^{2+} + 2e^{-}(anodic) \quad (1)$$

$$2H_2O + O_2 + 4e^{-} \rightarrow 4OH^{-}(cathodic) \quad (2)$$

$$2Fe + O_2 + 2H_2O \rightarrow 2Fe(OH)_2 \quad (3)$$

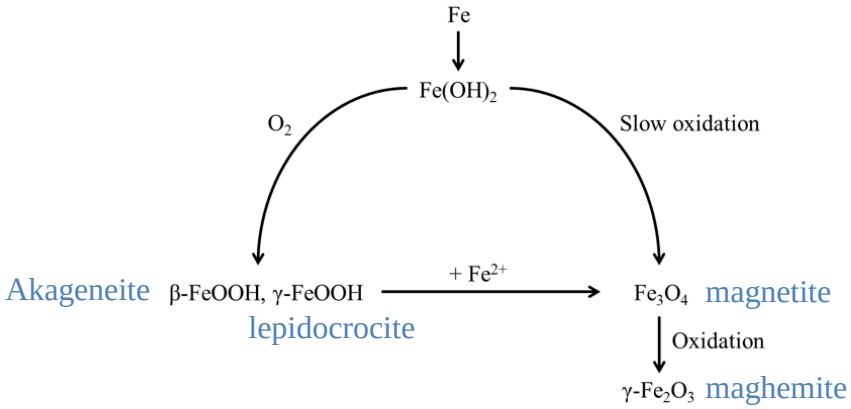


Figure 4-16. Corrosion reactions of the steel substrate under the coating films.

Huang, F.; Liu, J.; Deng, Z.J.; Cheng, J.H.; Lu, Z.H.; Li, X.G. Effect of Microstructure and Inclusions on Hydrogen Induced Cracking Susceptibility and Hydrogen Trapping Efficiency of X120 Pipeline Steel. Materials Science and Engineering A 2010, 527, 6997–7001, doi:10.1016/j.msea.2010.07.022.
Sørensen, P.A.; Kiil, S.; Dam-Johansen, K.; Weinell, C.E. Anticorrosive Coatings: A Review. J Coat Technol Res 2009, 6, 135–176, doi:10.1007/s11998-008-9144-2.

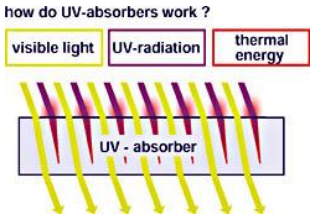
IMPACT AND CONTROL

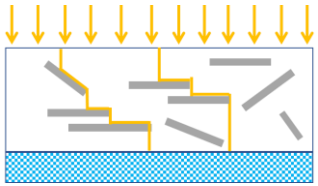
Impact

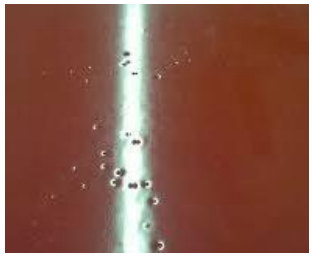
- Aesthetics, repair expense, loss of strength, safety incidence

Control measures

- Coatings with higher performance, e.g., specialty additives
- Tighter quality control of painting processes
- Additional coating layer to cover stochastic pores underneath
- Higher coating film thickness
- Better cleaning (lower Cl^-)
- Less corrosive deicing road salt







https://www.pcimag.com/articles/86462-uv-protection-and-coatings-for-plastics-in-the-automobile-industry
https://www.dcpaintsolutions.com/news/spray-painting-common-faults-and-misconceptions
https://www.shell.ca/en_ca/drivers/shell-canada-car-wash.html
https://environmentaldefence.ca/2019/02/06/salt-ernatives-options-keep-roads-clear-freshwater-clean-winter/#:~:text=Beet%20juice%20and%20cheese%20brine%20%E2%80%93%20a%20recipe%20for%20safe%20roads&text=Many%20cities%2C%20recognizing%20the%20corrosive,know%20icy%20conditions%20are%20coming.

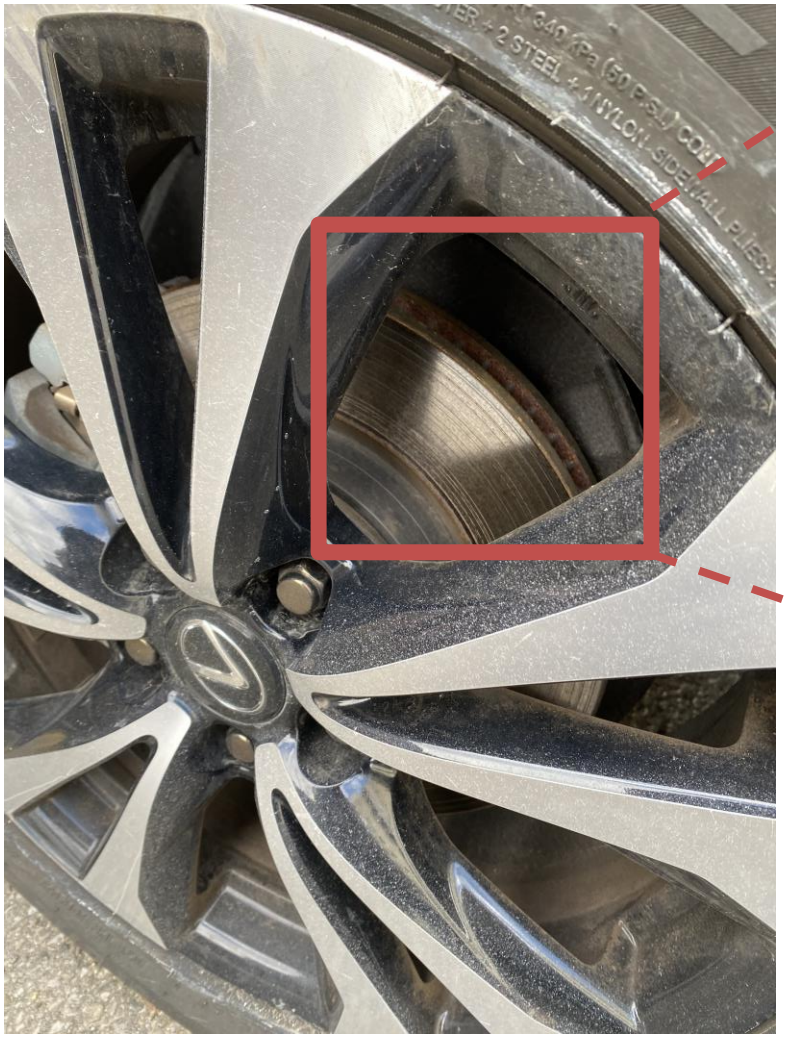
CORROSION OF BRAKE ROTOR

BRAKE ROTOR

- **What is brake rotor**
  - Circular discs connected to each wheel
  - Turing kinetic energy into thermal energy
  - Working with brake pad

- **Material**
  - Cast Iron
  - Carbon steel
  - Aluminum

CORROSION OBSERVED ON BRAKE ROTOR



Observation:

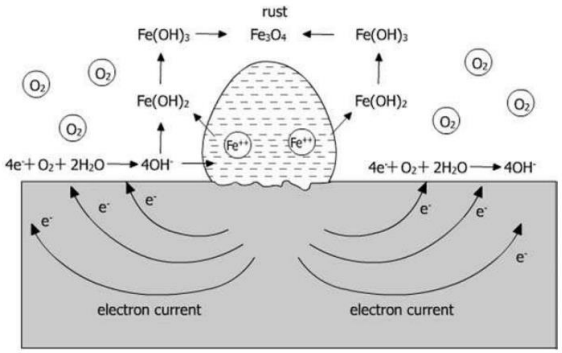
- brown/red/dark red iron corrosion products
- Surface been polished due to friction force from brake panel

POSSIBLE CORROSION TYPES

Atmospheric corrosion (uniform)

Damp/wet atmosphere: $\mathbf{O_2}$ and $\mathbf{H_2O}$

- $Fe^{2+} + OH^- \rightarrow Fe(OH)_2$
- $4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$
- $4Fe(OH)_2 + O_2 \rightarrow 2Fe_2O_3 \cdot H_2O + 2H_2O$



Ahmad, Z.; Macdonald, D. D. *Principles of Corrosion Engineering and corrosion control*; Butterworth-Heinemann: Oxford, 2013.

POSSIBLE CORROSION TYPES

Atmospheric corrosion (uniform)

- **Corrosion from vehicle exhaust gas:**
  - **NO_x (NO_2 mainly) and SO_2**
    - At high RH, formation of $FeSO_4$
    - At 50% RH, formation of $FeSO_4 \cdot 7H_2O$
      - NO_2 provides liquid drop with $Fe(NO_3)_{(aq)}$
      - Depassivation of the metal by SO_2
- **Corrosion rate**
  - Cyclic load

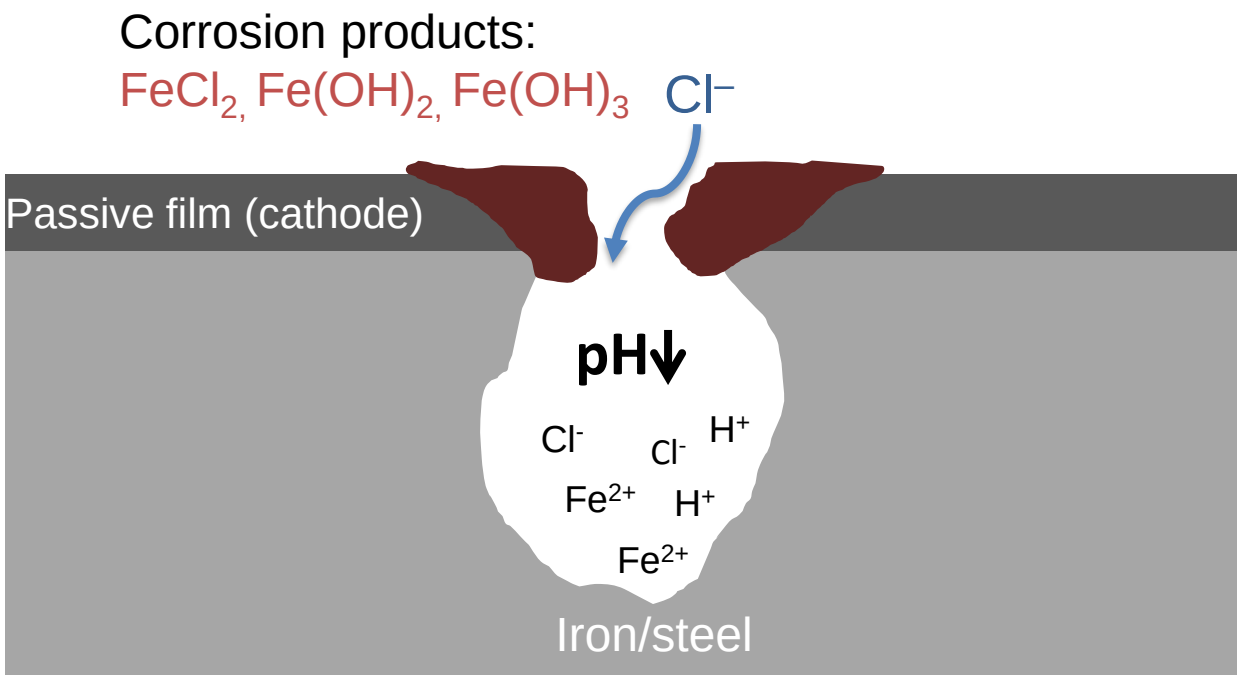
Arroyave, C.; Morcillo, M. The Effect of Nitrogen Oxides in Atmospheric Corrosion of Metals. *Corrosion Science* **1995**, *37* (2), 293–305.

POSSIBLE CORROSION TYPES

Pitting corrosion (Cl^- as aggressive ion)

Road salt

-**NaCl (98%)** and $CaCl_2$, $MgCl_2$ (2%)



Passive film: $Fe(OH)_3$

Materials engineering. https://www.substech.com/dokuwiki/doku.php?id=pitting_corrosion (accessed Feb 3, 2023).
Ansari, T.Q., Luo, JL. & Shi, SQ. Modeling the effect of insoluble corrosion products on pitting corrosion kinetics of metals. *npj Mater Degrad* **3**, 28 (2019). https://doi.org/10.1038/s41529-019-0090-5

POTENTIAL PROBLEMS DUE TO CORROSION

- A nasty sound when the brakes are first applied after sitting for a period and becoming coated with rust.
- Alterations to the geometry of the brake disc. This can lead to excessive noise and vibrations. In the automotive industry, this phenomenon is known as “cold judder”.
- Increased stopping distances.
- Corrosion adhesion.

PREVENTIVE MEASURES

- Use a surface coating such as anticorrosive paint, galvanizing, or creating an alternative barrier to protect the underlying metal.
- Annealing of the brake disc:
  - Putting the brake disc into a furnace containing nitrogen and methanol.
  - After the heat treatment, the brake disc is introduced to a cooling furnace.
  - Air exchange treatment.
  - ensures even heating, uniform cooling, and free of oxidation.

https://www.allrotors.com/blog-31-coated-vs-uncoated-brake-rotors-is-rust-preventive-coating-worth-it

PREVENTIVE MEASURES

ALTERNATIVE MATERIALS

- Composite brake discs reinforced with carbon fiber. They show excellent braking performance even under extreme conditions and are very lightweight.

- A more cost-effective alternative material for brake discs is aluminum. Pure aluminum has low resistance to wear and abrasion, but this can be improved by formulating hard-wearing alloys.

- PEO coatings for brake discs. These coatings are designed to increase wear resistance and provide corrosion protection.

https://www.allrotors.com/blog-31-coated-vs-uncoated-brake-rotors-is-rust-preventive-coating-worth-it

PREVENTIVE MEASURES

- Park your car in a dry, moisture-free space, such as a temperature-controlled garage.

- During snowy climates, run your vehicle through the car wash regularly to remove road salt that can corrode brake components.

https://www.wagnerbrake.com/technical/parts-matter/automotive-repair-and-maintenance/why-rust-on-my-brakes.html

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