REFRIGERATOR CARBON STEEL CORROSION ANALYSIS

Investigating Polymer Coating Breakdown and Moisture Effects

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Executive Summary

The intended audience for this report is LG Electronics' appliance design and materials engineering teams, along with corrosion specialists in the consumer appliance industry. The findings offer insight into corrosion mechanisms affecting product durability and warranty reliability.

Polymer-coated low-carbon galvanized steel is commonly used in household refrigerators due to its cost efficiency and moderate corrosion resistance under normal operating conditions. However, premature rusting was observed around the ice tray area, where repeated moisture exposure and cleaning cycles have occurred. This project investigated the cause of this failure, focusing on how the breakdown of the polymer coating allows chloride ions to penetrate and initiate under-film pitting corrosion. Understanding this mechanism was essential to improving materials selection, coating performance, and product longevity in the future design of refrigerators.

To analyze the failure, this project included a macroscopic inspection, environmental assessment, and correlation with published corrosion standards (ASTM B117). Using data from various literature sources and visual evidence, it was found that the chloride-rich local environment induced pitting corrosion and crevices around the icetray, facilitating rapid corrosion growth. This approach connected behavior seen in a corrosion laboratory to consumer product performance, offering insights into how coating degradation can be predicted and mitigated.

Some recommendations include adding a slope or drainage paths near the dispenser, incorporating a hydrophobic gasket or sealant into the capillary path at the seam, improving surface pretreatment, and ensuring minimum coating thickness and edge sealing around the dispenser assembly. At the consumer level, it is recommended to periodically wipe and dry the area under the tray to avoid long-term moisture exposure.

Introduction

The premature corrosion near the refrigerator ice dispenser prompted a detailed failure study to understand the underlying mechanisms responsible for the observed degradation. While household appliances are expected to withstand repeated exposure to moisture, this case demonstrated unexpected rust formation and coating failure in a routine-use area. The purpose of this failure analysis is to determine the corrosion mechanism, identify the factors that initiated coating delamination, and provide recommendations to eliminate similar failures in future refrigerator designs.

Background

This project examines the failure of polymer-coated galvanized steel surfaces near refrigerator ice trays, which is caused by pitting corrosion, a type of localized corrosion that weakens both the strength and appearance of the material. The issue is important to analyze because appliance-grade coated steels are expected to provide long-term corrosion protection under regular household use. However, many consumer reports and warranty claims mention early rusting around areas prone to moisture. Understanding how this failure occurs can help develop more effective material coatings and design strategies to enhance the longevity of household appliances.

The main component, the refrigerator base that surrounds the ice tray, is exposed to cycles of moisture, condensation, stagnant water, and periodic cleaning with chemicals. These conditions can weaken the anti-corrosive coating, which is typically made of pigmented polypropylene (Polyrocks, 1970). Over time, these conditions can cause degradation, allowing chloride ions from tap water or cleaning agents to trigger pitting corrosion, which spreads quickly once the zinc film is broken down. This scenario offers a practical example of how material choices, surface treatments, and environmental factors interact in real-world consumer products.

Since the refrigerator's surface is magnetic, the substrate is consistent with mild, low-carbon steels commonly used in appliance doors, and XRF analysis confirmed the presence of a zinc-rich coating rather than the chromium expected in stainless steel. The analyzed substrate is therefore classified as a galvanized low-carbon steel with a polymer topcoat, used for both aesthetic appeal and corrosion protection. Galvanized steels are known to be vulnerable to under-film corrosion when moisture accumulates at coating defects, as zinc dissolution creates locally aggressive microenvironments. The surrounding ice-tray region experiences frequent wetting, stagnant water, detergents, and thermal cycling, all of which promote delamination of the polymer coating. Once the coating lifts, residual chloride ions concentrate in the trapped moisture film, accelerating pitting corrosion on the exposed steel surface. The chemical composition of typical galvanized appliance steel is in Table 1.

Previous research has shown that even minor coating defects can serve as starting points for corrosion under thin electrolyte films. Once a pit develops, the confined geometry creates a low-pH, high-chloride microenvironment, intensifying the damage (Revie & Uhlig, 2008). This case shows how material properties, surface treatments, and environmental factors interact in real-world service to cause localized corrosion.

Table 1. Typical chemical composition of low-carbon steel used for galvanized sheet steel (American Society for Metals, 1990)

Element	Composition (%)
C	0.05 – 0.15
Mn	0.20 – 0.60
Si	0.01-0.30
P	< 0.03
S	< 0.03
Fe	Balance

Table 2. Materials Properties for Polypropylene (MatWeb, n.d.)

Property Name	Property Value
Density	0.88 – 2.40 g/cc
Water Absorption	0.00 – 0.800 %
Moisture Absorption at Equilibrium	0.100%
Moisture Absorption at Saturation	0.100%
Maximum Moisture Content (120ºC)	0.250

Methods

A multi-stage investigation was conducted to characterize the corrosion failure observed near the refrigerator ice tray, combining macroscopic inspection, environmental evaluation, literature review, and preliminary modeling of corrosion behavior.

The first step was to conduct a visual and macroscopic evaluation of the affected zone. Surface observations were made using a high-resolution Digital Single-Lens Reflex (DSLR) camera to document rust formation and coating delamination. Observations focused on identifying the location and pattern of corrosion relative to areas exposed to stagnating water and cleaning agents. Image analysis software was used to estimate the size and distribution of the corroded regions.

An environmental assessment using a standard water hardness tester was performed on the water being output from the fridge water dispenser. Furthermore, the area around the ice tray was monitored for temperature and humidity changes, and the frequency of water buildup was recorded. Household cleaning products commonly used in that area were reviewed for chloride-containing agents, as these are known to cause pitting in low-carbon steel.

X-ray fluorescence (XRF) was performed to identify the elemental composition of the refrigerator panel and confirm the steel grade. An Olympus Vanta handheld XRF analyzer was used to obtain non-destructive surface measurements of the exposed substrate. Each scan was collected for approximately 5 seconds, and the instrument quantified the major alloying elements based on characteristic peaks.

To place the findings in context, results were compared with corrosion mechanisms described in the literature and with conditions defined by ASTM B117 (American Society of Testing Materials, 2011), which outlines the standardized salt-spray exposure used to accelerate coating degradation. The published data on chloride-induced corrosion rates in low-carbon steels were used to approximate how similar conditions could lead to pit initiation over time (Revie & Uhlig, 2008).

A preliminary Root Cause Analysis was also conducted. Potential contributing factors were organized under four main categories:

- Design: Insufficient drainage geometry near the ice tray allowed stagnant water to persist
- Manufacturing: The coating application or adhesion may have been inadequate for the intended moisture exposure (Totten, Xie, & Funatani, 2004)
- Operation: Regular use of chloride-based cleaners accelerated coating breakdown
- Maintenance: Limited consumer inspection or cleaning under the tray allowed corrosion to progress unnoticed

Description of Engineering Failure

The corrosion event occurred on the refrigerator door panel directly beneath the ice dispenser. Before the onset of visible corrosion, minor discoloration and dulling of the polymer coating were seen. Over time, the coating began to bubble and lift, more specifically along the horizontal seam below the dispenser seam. This delamination allowed moisture to accumulate beneath the coating, forming a concealed electrolyte layer in contact with the galvanized steel substrate. The dominant failure mode was under-film pitting corrosion initiated at a coating defect along the horizontal seam.

As the degradation progressed, the coating blisters expanded and ruptured, exposing areas of iron oxide. Mineral deposits from evaporated tap water accumulated along the seam and on adjacent surfaces, providing visual evidence of repeated wetting and slow-drying cycles. Ultimately, the coating lost adhesion in a localized region, leaving bare steel exposed to the environment and accelerating corrosion.

The failure developed over an extended period, with the blistering expanding along the length of the seam, indicating months or years of corrosion. The combination of water retention, dissolved ions, and crevice-like geometries enabled corrosion to progress beneath the coating, remaining hidden until significant material damage occurred.

Results

Qualitative Results

Visual examination of the refrigerator door revealed localized corrosion concentrated around the ice dispenser bezel and the horizontal seam directly beneath it, as shown in Figure 1. Areas along the lower edge exhibited blistering and bubbling of the polymer coating, with visible Iron Oxide (rust product, Fe_2O_3) accumulating beneath the lifted regions. The blisters were irregularly shaped and distributed primarily along moisture-retaining geometries where water from the icetray stagnated. The surrounding coating surface showed a dull, uneven appearance compared to the adjacent unaffected regions, indicating loss of adhesion and early under-film corrosion activity.

Closer inspection confirmed that the initial corrosion was beneath the protective polymer coating and was beginning to propagate outward, producing rough, porous surface features. In several locations, the coating fully detached, exposing the underlying metal surface, where pitting corrosion was seen. Figure 3 shows the progressive stages of this coating degradation. Figure 3a shows the early blistering, while Figure 3b shows complete delamination and pit exposure at the same site. The pit morphology was shallow but sharply defined, consistent with chloride-induced pitting in galvanized low-carbon steel.

The affected zones correspond closely to areas of repeated wetting and drying during everyday refrigerator use. Mineral residue on the drip tray and along the lower seam indicates long-term moisture retention and the presence of dissolved ions that can initiate localized pitting corrosion. These observations, combined with literature data and environmental conditions measured during inspection, confirm that the primary degradation mechanism was localized pitting and under-film corrosion driven by trapped moisture and chloride accumulation near the dispenser area.

The environmental analysis indicated that the measured hardness of water (Calcium Carbonate concentration) averaged 145 mg/L $CaCO_3$, indicating moderately hard water according to standard classification. The presence of dissolved calcium and carbonate ions supports the formation of white mineral deposits observed on the tray surface and seam regions (Figure 1). These residues, when re-wetted, can retain chloride and further promote localized corrosion under thin electrolyte films. The moderately hard water, combined with incomplete drying and repeated wetting, creates favorable conditions for corrosion in low-carbon steel.

The elemental analysis confirmed that the refrigerator panel is not stainless steel, but rather a galvanized low-carbon steel. The measured composition showed a high Fe content (~74.6 wt%) and a significant Zn fraction (~23 wt%), characteristic of zinc-coated appliance sheet steel. Since chromium was not detected, the coating substrate was not a stainless-steel alloy. Instead, the spectrum and quantitative results are consistent with a galvanized coating applied over mild steel substrates. Table 4 presents the XRF results, and Figure 2 shows the location and the spectra measured there.

Figure 1. Macroscopic images showing corrosion and coating degradation on the refrigerator door, near the ice dispenser. (a–d) Areas along the dispenser bezel and lower seam exhibit coating blistering, rust product buildup, and under-film corrosion.

Table 3. Measured calcium carbonate concentrations in water samples near the ice tray region.

Reading #	$CaCO_3$ Concentration (mg/L)
1	145
2	134
3	156

Figure 2. XRF scan area on the refrigerator panel (left) and corresponding elemental spectrum (right) used to determine the material composition.

Table 4. XRF elemental composition and associated ± 3σ uncertainty for the refrigerator panel.

Element	Composition (%)	± 3σ
Ti	2.04	0.45
Mn	0.19	0.13
Fe	74.63	0.70
Ni	0.12	0.13
Zn	23.02	0.62

Figure 3. Progressive coating delamination was observed near the refrigerator dispenser area. (a) Early-stage blistering and discoloration indicate the initiation of under-film corrosion. (b) Enlarged view of the same site showing complete coating detachment and exposure

Simulations and Quantitative Analysis

To evaluate how the geometry of the ice tray and the material system contribute to coating delamination, a thermal-mechanical simulation was performed in SolidWorks 2025. A simplified geometry was modeled as a low-carbon, galvanized steel substrate with a 0.10 mm polypropylene coating bonded to its surface. A raised seam feature was incorporated into the steel geometry to simulate the horizontal ledge found beneath the ice-dispenser. Standard materials properties were used from the included SolidWorks libraries.

A two-step simulation approach was used, consisting of a steady-state thermal study with a uniform 20ºC temperature increase to represent typical compressor cycling and daily temperature fluctuations at the door surface. Next, a static structural analysis imported the results from the thermal study to compute strains and stresses due to differential thermal expansion. The back face of the steel plate was fixed to represent attachment to the overall refrigerator structure. A refined mesh was used along the seam and coating interface to capture the behavior under the applied conditions. The simulation setup is shown in Figures 4 and 5.

The results showed a strong localization of thermal strain at the seam where the coating transitions over the raised edge. The measured strain values were significantly larger than in the flat region, consistent with polymer expansion being constrained by the metal and the geometry. The elevated strains can model tensile and shear stresses at the interface and are sufficient to initiate adhesion loss. Figures 6 and 7 show the deformed material after the simulation, with the polymeric coating elongated following temperature cycling. Once the adhesion is compromised, moisture can penetrate the gap, which dissolves the underlying zinc coating, and initiate under-film corrosion.

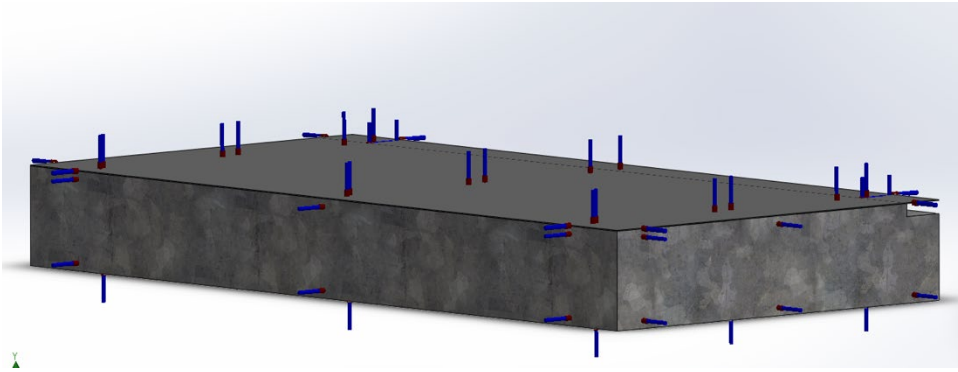

Figure 4. Thermal analysis setup showing the applied uniform temperature load and bonded contact conditions between the polymer coating and galvanized steel substrate.

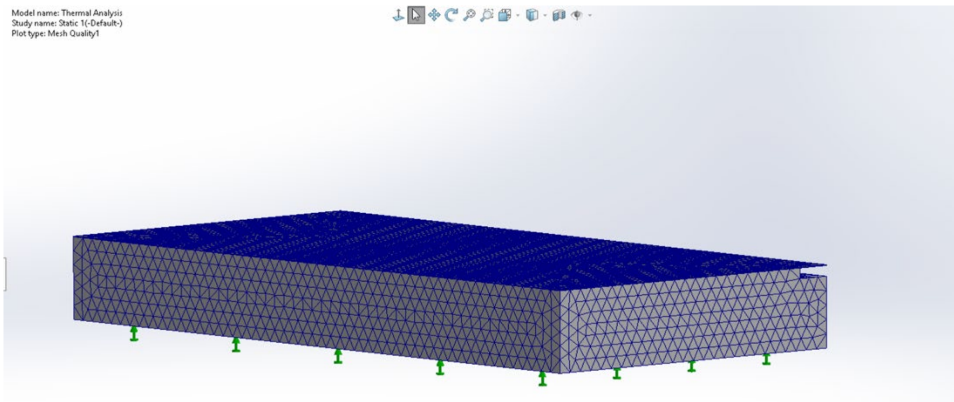

Figure 5. Static study setup with refined mesh and fixed constraint applied to the rear steel face to simulate attachment to the refrigerator structure.

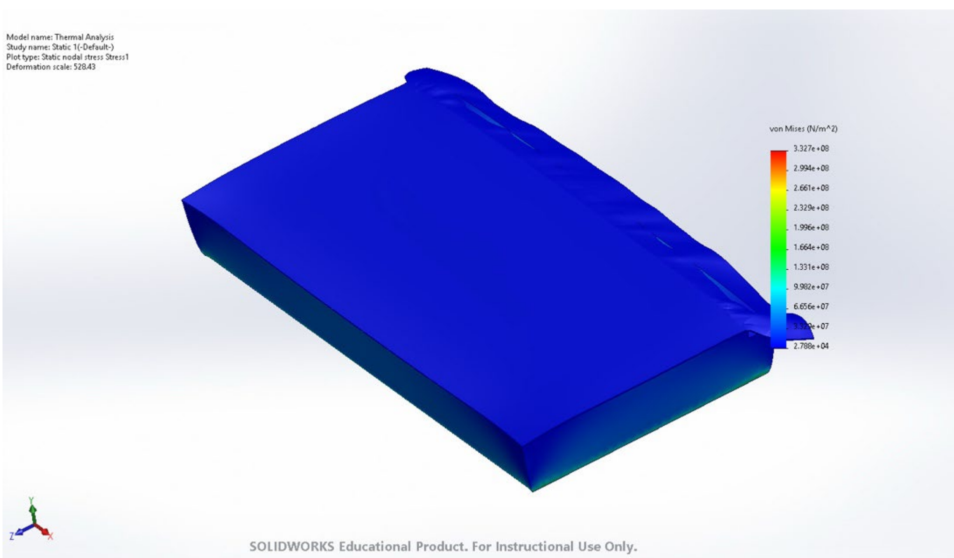

Figure 6. Von Mises stress distribution resulting from differential thermal expansion between the polymer coating and steel substrate.

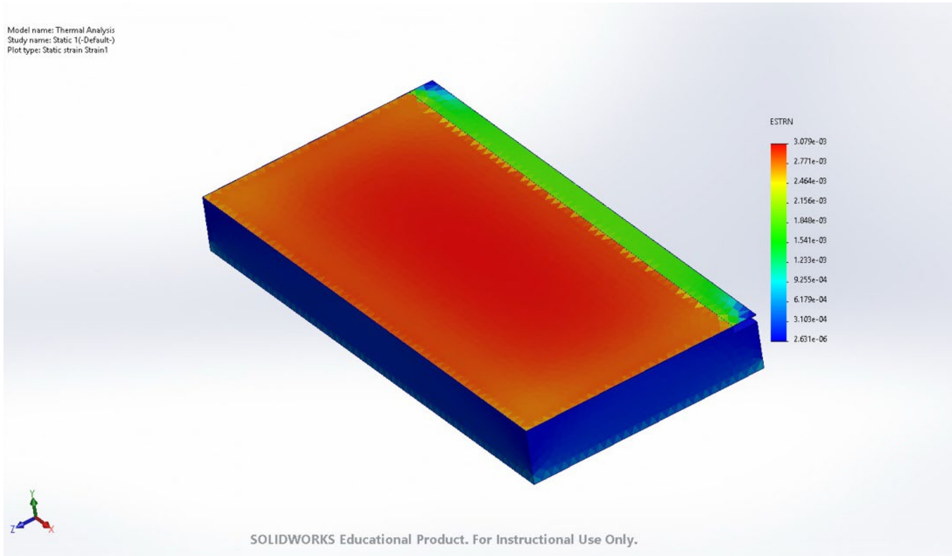

Figure 7. Thermal strain distribution showing high strain localization at the seam and coating edge.

Discussions and Conclusions

Discussion

The results confirm that the corrosion observed near the refrigerator ice dispenser was driven by a combination of design geometry, coating adhesion limitations, and moisture retention during service. Once the coating delaminated, the underlying zinc layer was locally consumed, exposing the bare steel, causing rapid corrosion in the presence of trapped water and dissolved ions. Since galvanized steel does not rely on a chromium-based passive film, the corrosion mechanism followed the expected progression of zinc dissolution and under-film rusting rather than passive-film breakdown.

The Root Cause Analysis (RCA) indicated the four key contributing factors (Table 3). The design of the dispenser region included a horizontal seam and a tight bezel gap, where moisture easily pooled and created conditions conducive to corrosion. From a manufacturing perspective, the polymer's coating edge thickness and adhesion were insufficient to withstand continuous cycles of wetting and drying. Operationally, household tap water with an average hardness of ~145 mg/L $CaCO_3$ supplied a constant source of ions that concentrated as white residue, supporting corrosion when re-wetted. Finally, from a maintenance standpoint, although cleaning practices were employed, the area was rarely entirely dried after use, allowing the corrosion to continue.

Root Cause Analysis

1. Why was rust observed on the refrigerator door?
   This was due to the steel beneath the polymer coating becoming exposed and corroding.
2. Why did the steel become exposed?
   Because the polymer coating delaminated, and the underlying zinc layer was consumed.
3. Why did the coating delaminate and the zinc layer corrode?
   Because moisture had accumulated beneath the coating, it created a sustained electrolyte film that dissolved the zinc coating.
4. Why did moisture accumulate in this region?
   Because the dispenser geometry includes a flat horizontal seam and a tight bezel gap, which traps water.
5. Why was the geometry unable to shed water effectively?
   The design lacked drainage paths, sloped geometry, and edge sealing, resulting in moisture being trapped. Under these confined conditions, chloride-rich films create low-pH microenvironments that accelerate zinc dissolution and under-film pitting.

Table 5. Summary of Root Cause Analysis (RCA) factors contributing to localized corrosion.

Category	Contributing Cause	Evidence
Design	Flat ledge seam near ice dispenser trapped water with no drainage path.	Figures 1-2.
Manufacturing	Marginal coating adhesion and coverage at edges; inadequate pretreatment for splash zone exposure.	Blistering and under-film corrosion initiating at edges.
Operation	Moisture exposure and mineral-rich tap water concentrated ions during wet/dry cycles.	$CaCO_3$ resides visible in images. Table 2 hardness measurements.
Maintenance	Limited inspection or drying after use allowed corrosion to initiate and propagate.	Long-term staining and stable rust growth over years.

Recommendations:

These recommendations directly target LG's design and materials selection process and are intended to reduce warranty claims associated with moisture-driven corrosion.

- Design improvements: add slope or drainage paths near the dispenser and incorporate a hydrophobic gasket or sealant to the capillary path at the seam.

- Manufacturing controls: Improve surface pre-treatment and ensure minimum coating thickness and edge sealing around the dispenser assembly.
- User maintenance: Encourage users to periodically wipe and dry the area under the tray to avoid long-term moisture exposure.

Conclusions

This failure investigation determined that corrosion on the galvanized low-carbon steel refrigerator door was driven by moisture retention and subsequent coating delamination. The combined effects of design geometry, manufacturing variability, and environmental exposure created localized microenvironments that promoted zinc dissolution and under-film pitting. Once the zinc layer was consumed, the exposed steel corroded rapidly.

This case shows how appliance-grade coated steels can fail when trapped moisture and inadequate coating protection are present. The results emphasize the importance of applying corrosion-engineering principles, such as drainage-aware designs, proper edge sealing, and better coating adhesion, into consumer product development. Future refrigerator designs need to account for actual moisture retention conditions, not just idealized scenarios, to prevent similar failures.

Appendix

Figures:

Tables:

Bibliography

American Society for Metals International. (2006). *Corrosion: Environments and Industries*. Retrieved from https://doi.org/10.31399/asm.hb.v13c.9781627081849

American Society of Testing Materials. (2011). *ASTM B117*. Retrieved from Standard Practice for Operating Salt Spray (Fog) Apparatus: https://www.galvanizeit.com/uploads/resources/ASTM-B-117-yr11.pdf

AZO Materials. (2012, 09 26). *Grade 304 Stainless Steel: Properties, Fabrication and Applications*. Retrieved from AZO Materials: https://www.azom.com/article.aspx?ArticleID=6809

Finch, C. (1990). *Polymer handbook: Third edition Edited by J. Brandrup and E. H. Immergut, Wiley-Interscience, Chichester, 1989. pp. ix + parts I to VIII, price £115·00/$;175·00. ISBN 0–471–81244–7*. Retrieved from British Polymer Journal: doi.org/10.1002/pi.4980230318

MatWeb. (n.d.). Retrieved from Overview of materials for Polypropylene, Molded: https://www.matweb.com/search/datasheet.aspx?MatGUID=08fb0f47ef7e454fbf7092517b2264b2&ckck=1

OpenAI ChatGPT. (2025). Prompt used, with uploaded document: "read this and suggest any changes".

Polyrocks. (1970, 01 01). Retrieved from Polyrocks: https://www.polyrocks.net/news/plastics-commonly-used-in-refrigerator.html

Revie, W. R., & Uhlig, H. H. (2008). *Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering: Fourth Edition*. Retrieved from doi.org/10.1002/9780470277270

Totten, G., Xie, L., & Funatani, K. (2004). *Handbook of Metallurgical Process Design*. Retrieved from doi.org/10.1201/9780203970928