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Metal, Moisture, And Mystery:

The Curious Case of The Corroding phone Charger Pin

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ABSTRACT

In metal-based electrical devices, corrosion poses a significant challenge and can be instigated by numerous factors such as moisture exposure, contact with salts and chemicals, and the occurrence of galvanic corrosion when different metals interact in an electrolyte-rich environment. Manufacturing defects, including substandard materials or insufficient protective coatings, can also contribute to corrosion. To combat this, it's essential to uphold cleanliness and dryness, conduct regular gentle cleaning to eradicate potential corrosive substances, and store the devices appropriately in cool, dry areas.

The paper interestingly explores this phenomenon, with a case study focusing on the corrosion of a specific pin in a Phone charger as compared to the other seven pins on the same side of the charger.

Key words: Coating, Corrosion, Phone charger pin, atmospheric corrosion.

INTRODUCTION

The persistent issue at hand involves a recurring challenge: a specific pin within the charging mechanism consistently turns black, subsequently ceasing the function of the charger on the respective side. The same problem unfailingly manifests on the alternate side, leading to the complete and total failure of the phone charger. This issue is not isolated, as it has occurred with several other chargers of the same type, demonstrating a pattern of consistent malfunction. Considering these events, this study embarks on a comprehensive exploration to identify the possible causes behind the consistent blackening of the particular pin. By meticulously analyzing various possible factors and contributors to this issue, the study aims to uncover insights and understanding that can lead to practical and effective solutions.

CASE STUDY

INTRODUCTION

In the quest to comprehend the underlying cause of the pin blackening, a detailed and comprehensive comparative study was initiated. This investigation encompassed the evaluation of three distinct types of charging cables: a corroded charger exhibiting the blackening issue on the pin, a brand-new charger cable from the original manufacturer, and an original manufacturer approved third-party vendor new charger cable procured from a local store. Each cable underwent an exhaustive analysis to discern the specific characteristics and conditions contributing to the blackening and corrosion.

By juxtaposing the corroded cable with both a new charging cable from the original manufacturer and a cable from an external vendor, the study aimed to identify any notable disparities or similarities. This would help in understanding whether the problem lies in the manufacturing process, the material composition, or other external factors. The intricate evaluation of each cable type provided a comprehensive perspective, shedding light on the multifaceted elements involved in the issue and paving the way for identifying effective solutions to prevent the blackening of the pins in the future.

LAB TESTING

This study embarks on a journey to unravel the mysteries surrounding the blackening of charger pins by employing an extensive and methodical approach. Utilizing advanced analytical tools and methodologies, including Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS), the study examines the corroded and unaffected pins from both the original and third-party manufacturers. By delving into the elemental composition of the corrosion products and conducting a comparative study of new and corroded pins, the investigation aims to shed light on the underlying causes of pin blackening. The findings from this study endeavor to provide a foundation for the development of effective solutions, ensuring the longevity and reliability of charging cables in the future.

Stereoscopic Examination of the Corroded Charger

Upon conducting a visual assessment, it was observed that the fourth pin on side 1, and the fifth pin on side 2 (or alternatively, the fifth and fourth pins when counted from the opposite ends, respectively) exhibited signs of blackening. This physical change indicated potential damage or corrosion to these specific pins on the charger.

To ascertain the details of this apparent damage, a thorough examination of the corroded pins was undertaken using a stereoscopic microscope. Figure 1 presents a clear visualization of the corrosion on the fourth pin on side 1. This image starkly highlights the contrast between the corroded pin and its undamaged counterparts, revealing the significant wear and tear it has undergone. This figure underscores the evident corrosion, reinforcing the initial visual assessment.

A closer inspection, as illustrated in Figure 2, provides an in-depth view of the corroded pin. This closer perspective uncovers a profound groove in the pin, suggesting the possible complete erosion of the material at this specific point due to extensive corrosion. This finding points towards the potential compromise in the functionality of the charger due to the damage to this pin.

Similarly, observations and examinations were extended to side 2 of the charger. As with the previous observations, noticeable corrosion was found on the fifth pin, as documented in Figures 3 and 4. The images capture the evident damage to the pin, mirroring the corrosion found on side 1, and further solidifying the conclusions drawn from the examinations conducted.

In summary, both detailed visual and stereoscopic examinations have affirmed the presence of significant corrosion on specific pins of the charger, possibly leading to its impaired functionality. The detailed figures provide substantial visual evidence of the corrosion, reinforcing the observations and conclusions drawn from this comprehensive assessment.

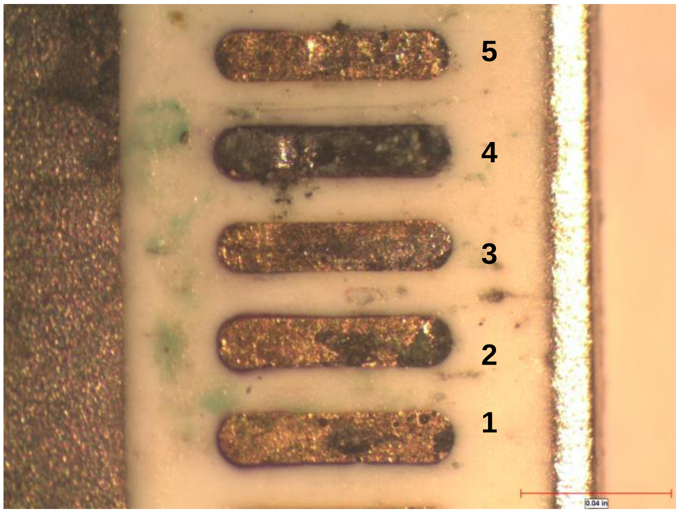

Figure 1: Stereoscope image showing that the fourth pin has corroded compared to the remaining pins (side 1). 25X

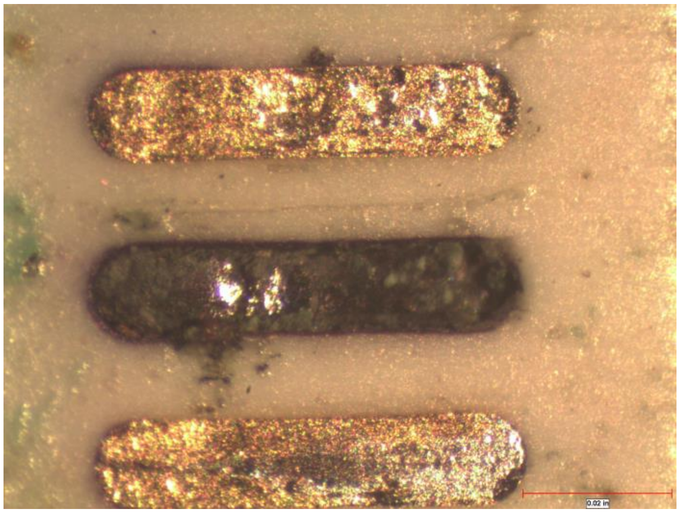

Figure 2: Closer view of fourth pin (side 1). 45X

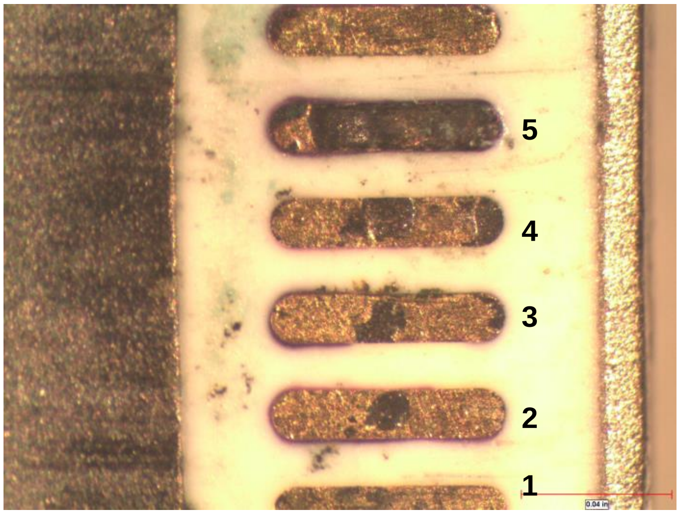

Figure 3: Stereoscope image showing that the fifth pin has corroded compared to the remaining pins (side 2). 25X

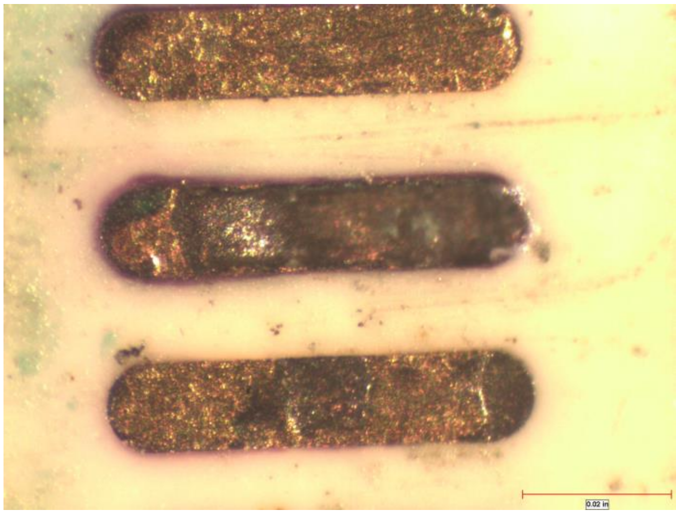

Figure 4: Closer view of fifth pin (side 2). 45X

<u>SEM and EDS Analysis of the Pins of Corroded Charger</u>

Following the stereoscopic examination, a more in-depth analysis of side 1 was conducted, utilizing SEM for a higher magnification inspection. This advanced microscopic technique allowed for a more granular view, uncovering details not visible to the naked eye or under lower magnification.

As shown in Figure 5, the SEM images provided a clear and enhanced view of the fourth pin, affirming the visible corrosion observed earlier. The highly magnified image accentuated the corroded surface, adding concrete visual evidence to support the initial observations.

Figure 6 further solidifies these findings. The SEM images vividly captured the extent of the damage to pin 4, confirming the total erosion of the material at this specific location. The advanced imaging allowed for a conclusive determination, evidencing the complete degradation due to the relentless corrosion.

Despite the remaining pins appearing intact and uncorroded during the initial visual examinations, the SEM analysis brought forth unexpected findings. Figures 7 and 8 unveil that the coating on these pins had been eliminated, laying bare the underlying substrate which was in the process of corroding. This revelation, possible only under the high magnification and detailed imaging of SEM, emphasizes the deceptive extent of the corrosion. Even seemingly undamaged pins were undergoing a corrosive process.

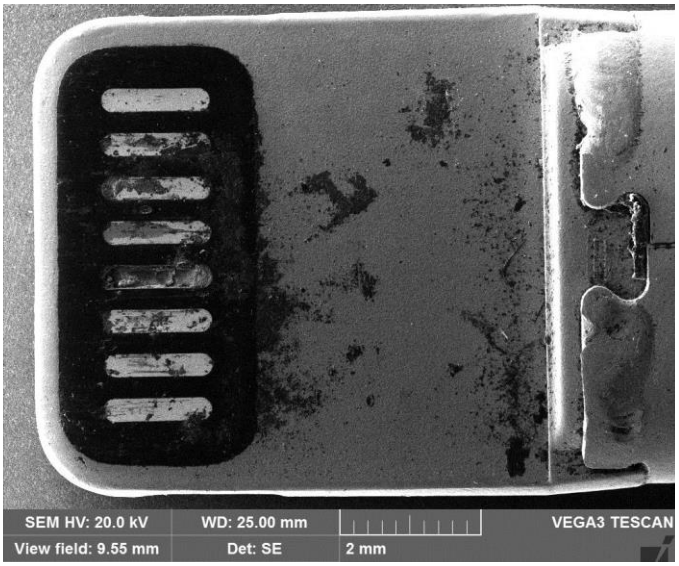

Figure 5: SEM image showing that the fourth pin has corroded compared to the remaining pins (side 1).

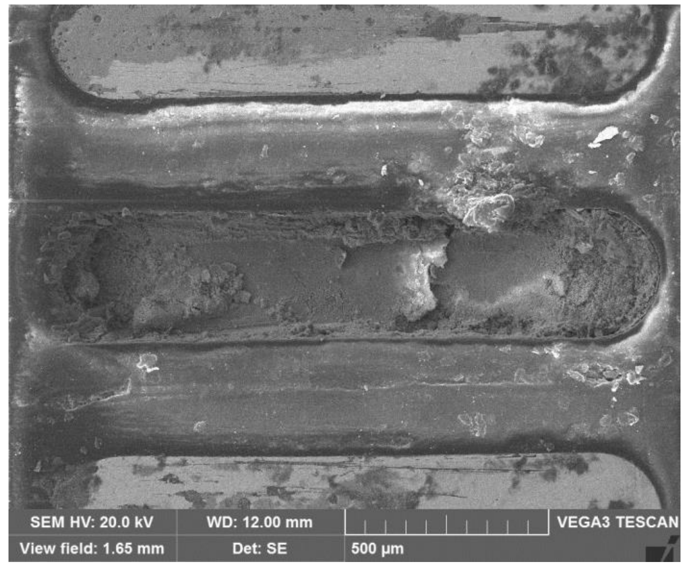

Figure 6: Closer view of fourth pin (side 1).

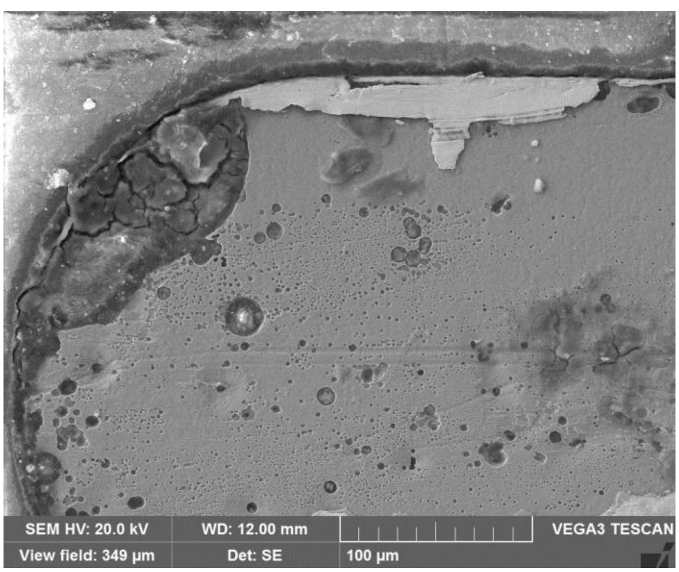

Figure 7: SEM image showing that the coating on the fifth pin is removed, and the underlying substrate started corroding.

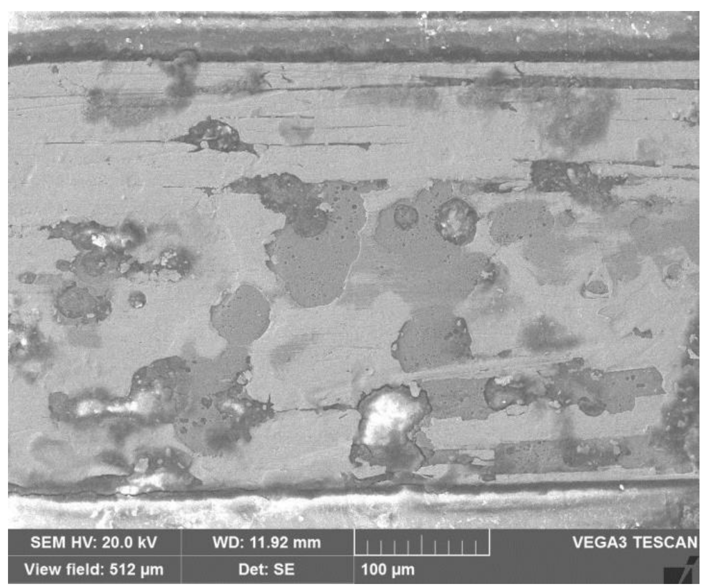

Figure 8: SEM image showing that the coating on the third pin is removed, and the underlying substrate started corroding.

EDS analysis was meticulously conducted on the chosen pins to delve deeper into understanding the potential causes behind the evident corrosion of the fourth pin, as well as to identify the material of the coating on the pins. This advanced analytical technique enabled the precise detection and measurement of the elements present in the samples, providing essential insights into the composition and possible corrosion processes.

Table 1 displays the EDS data obtained from the corroded pin. The findings revealed a significant presence of chlorides and copper was detected. This composition strongly suggests that the fundamental material of the pin is a copper alloy. The presence of chlorides hints at the likelihood of a chloride-induced corrosion process, which may be responsible for the extensive damage observed on this particular pin.

Proceeding to Table 2, the EDS analysis of a relatively unaffected pin is presented. The data elucidate that the exterior coating of the pin is made of gold. This finding is crucial as it indicates the protective layer intended to safeguard the underlying materials from corrosion and wear, highlighting the contrast with the corroded pin where this layer may have been compromised.

Table 3 further expands the investigative findings, presenting the EDS data from a partially corroded pin. The examination revealed an additional layer situated between the gold coating and the underlying copper substrate. This intermediary layer is identified as a nickel coating, serving as an additional protective or adhesive layer in the pin's composition. The detection of this layer provides a more comprehensive understanding of the pin's structure and the various materials involved in its composition.

Table 1: EDS data at the corroded pin revealed significant presence of chlorides.

Element	Weight %	Atomic %
C K	13.40	31.32
O K	18.52	32.49
AlK	0.24	0.25
SiK	0.31	0.31
P K	0.18	0.17
S K	0.25	0.22
ClK	15.38	12.18
FeK	0.88	0.44
NiK	4.27	2.04
CuK	46.57	20.58

Table 2: EDS data at the relatively unaffected pin revealed the coating on the pin is gold coating.

Element	Weight %	Atomic %
C K	9.36	43.89
O K	8.43	29.67
AlK	0.02	0.03
NbL	0.00	0.00
NiK	2.90	2.78
CuK	1.59	1.40
AuL	77.71	22.22

Table 3: EDS data at the partially corroded pin revealed the coating under the gold coating is nickel coating.

Element	Weight %	Atomic %
C K	3.29	13.59
O K	2.01	6.23
P K	0.20	0.33
FeK	0.69	0.61
NiK	93.80	79.24

SEM and EDS Analysis of the Cross-Sections

To conduct a comprehensive and detailed examination of the pin end of the corroded charger exhibiting the blackening issue, a multi-faceted approach was employed. This investigation involved comparing the afflicted charger with a brand-new charger cable from the original manufacturer and another new charger cable sourced from an original manufacturer approved third-party vendor. This method ensured a broad and diverse perspective, contributing to a more robust and reliable analysis.

In the initial phase, each charger cable was cold mounted and meticulously ground until the pins were visible. This process provided a clear and unobstructed view of the pins, facilitating an accurate and detailed analysis. The cold-mounted cross-sections were then polished to a mirror-like 1µ surface finish, further enhancing the visibility and examination capabilities.

To enhance the microscopic analysis, the polished cross-sections were etched with a Ferric Chloride ($FeCl_3$) solution. This etching process served to reveal the intricate details of the pin structure, offering a more comprehensive insight into the condition and composition of the pins.

Upon examining the etched cross-sections under an optical microscope, critical observations were made. Figure 9, captured at the corroded pin, provides a definitive view of the complete corrosion of the copper material. This image starkly highlights the extensive damage, underscoring the severity of the corrosion. A closer microscopic inspection, as shown in Figure 10, provides further revelations. Even the pin that appeared relatively unaffected to the naked eye was found to have undergone corrosion of the copper substrate. Additionally, this examination uncovered the presence of three distinct coating layers enveloping the copper substrate, providing further insights into the pin's construction and potential vulnerability to corrosion.

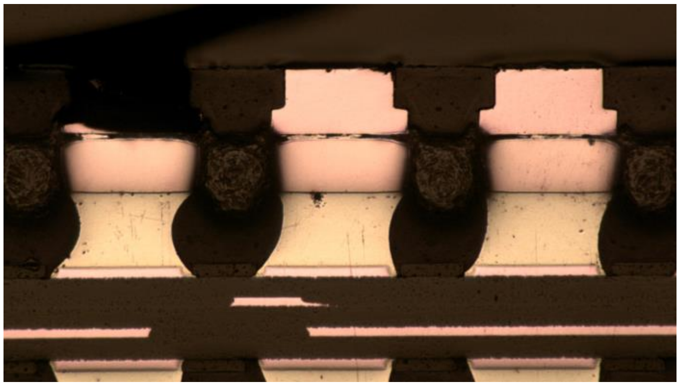

Figure 9: Photomicrograph showing that the fourth pin top copper material is totally corroded. Magnification: 50X

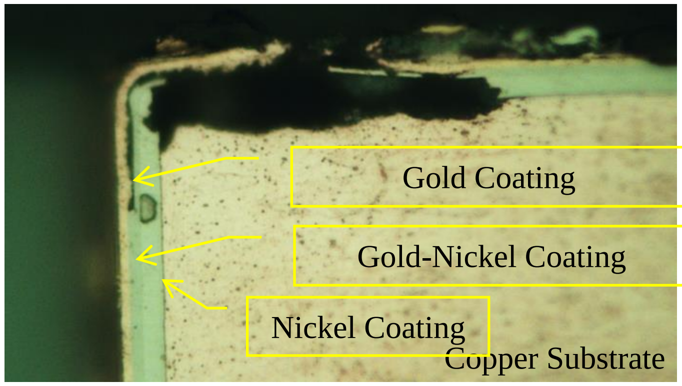

Figure 10: Photomicrograph of the unaffected pin to the naked eye also showed sign of corrosion. Magnification: 1000X

Figures 11 and 12 offer a photomicrographic exploration of the fourth, fifth, and sixth pins from the brand-new charger cable from the original manufacturer. Captured at 50X and 1000X magnifications respectively, these figures display the intact and undamaged structure and coating layers, offering a contrast to the corroded charger and presenting a benchmark for comparison.

Figure 11: Photomicrograph of the fourth, fifth, and sixth pins from the brand-new charger cable from the original manufacturer. Magnification: 50X

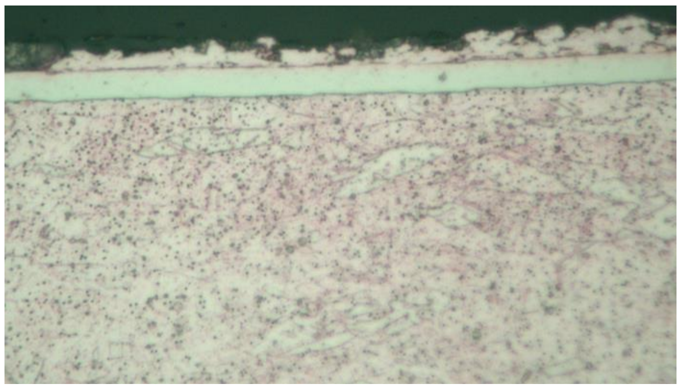

Figure 12: Photomicrograph showing three layers of coating on the copper substrate. Magnification: 1000X

In a parallel examination, Figures 13 and 14 present photomicrographs of the fourth and fifth pins from the brand-new charger cable obtained from the original manufacturer approved third-party vendor. These images, captured at magnifications of 50X and 1000X respectively, echo the findings from the original manufacturer charger, displaying the intact structure and coating layers and contributing to a comprehensive and multi-faceted analysis.

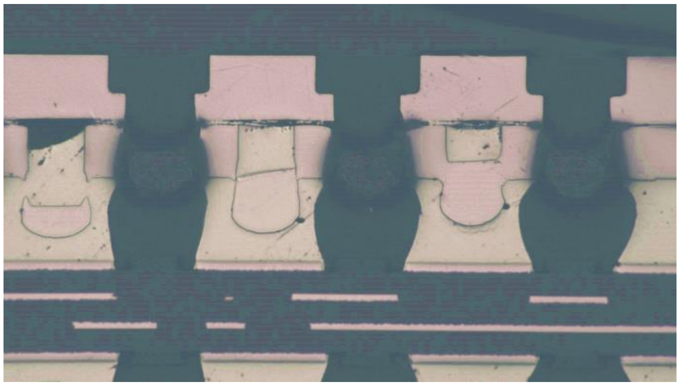

Figure 13: Photomicrograph of the fourth, and fifth pins from the brand-new charger cable from the original manufacturer approved third-party vendor. Magnification: 50X

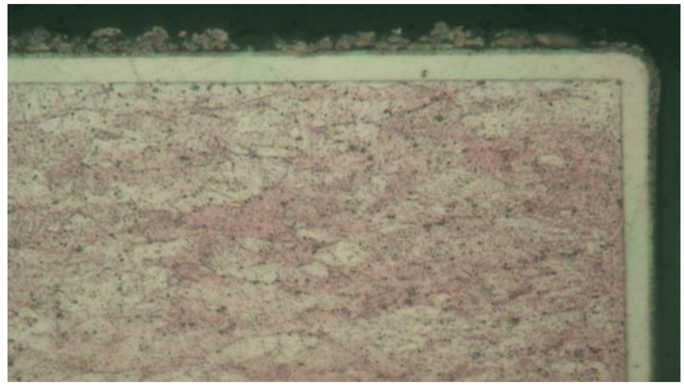

Figure 14: Photomicrograph showing three layers of coating on the copper substrate. Magnification: 1000X

Following the completion of the optical microscopic examination, the cross-sections were subjected to further in-depth scrutiny using SEM. Figure 15 provides a comprehensive SEM visualization of all the pins from the corroded charger. This broad view captures the overall state of each pin, offering a holistic perspective of the damage and condition of the entire set.

Moving into a more detailed analysis, Figure 16 is a focused SEM image specifically taken at the location of the corroded pins. This high-magnification image offers a stark and clear representation of the severe corrosion affecting the copper material. The SEM technology reveals the depth, spread, and intensity of the corrosion, presenting a comprehensive picture of the damage endured by the pins.

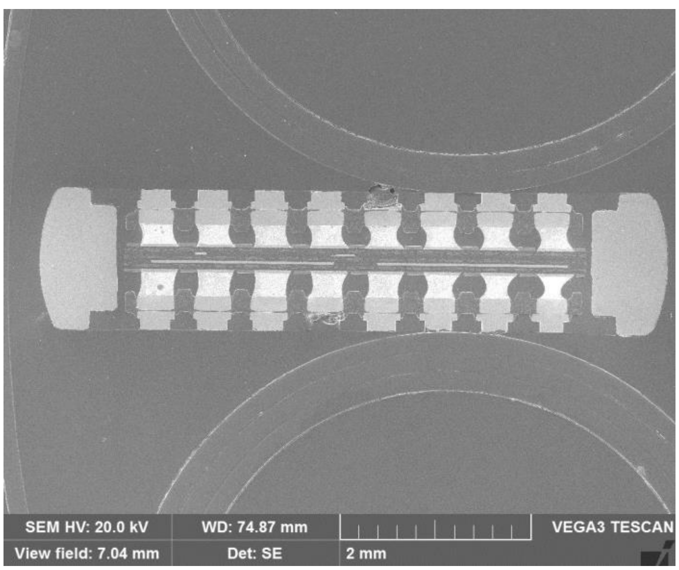

Figure 15: SEM image showing comprehensive visualization of all the pins from the corroded charger.

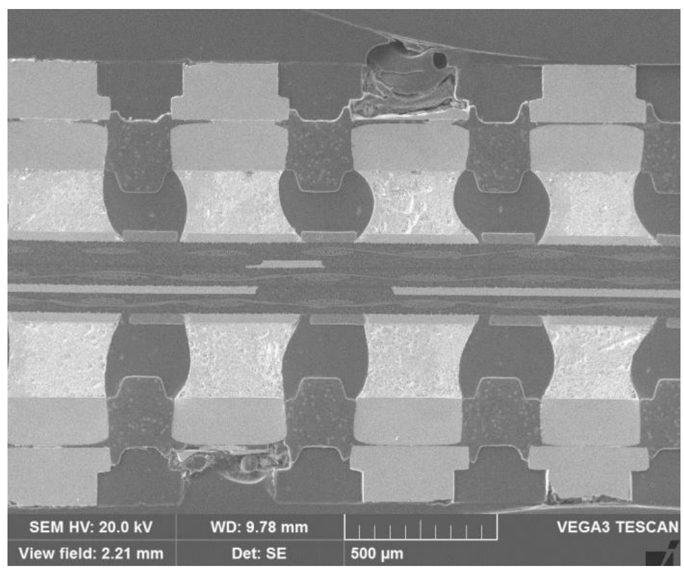

Figure 16: SEM image specifically taken at the location of the corroded pins.

Figure 17 provides an even more magnified examination of the corroded pin, accentuating the details of the corrosion damage. The degradation of the copper material is prominently showcased, providing profound insights into the nature and extent of the damage.

In contrast, Figure 18 displays the SEM image of a pin that was relatively unaffected, or at least less visibly damaged, when compared to the corroded ones. This image serves as a benchmark for comparison, emphasizing the difference in structural integrity, surface quality, and overall health of the pins. By juxtaposing the corroded and unaffected pins, a clear and undeniable contrast emerges, highlighting the disparity between the two states.

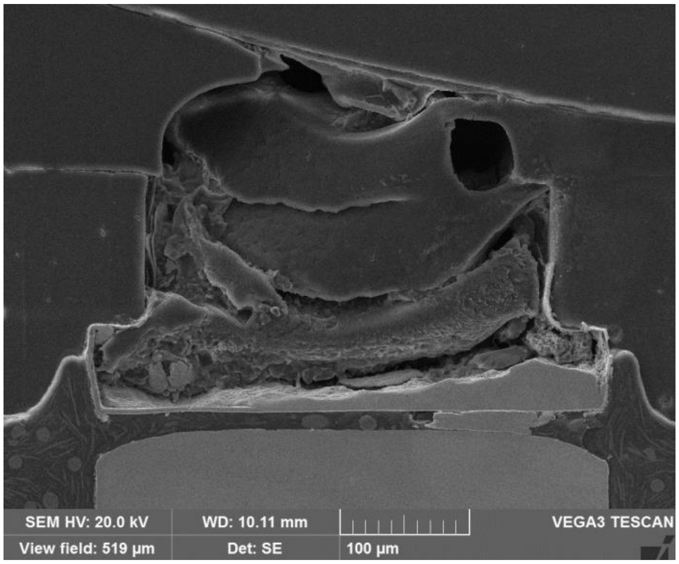

Figure 17: SEM image clearly showing that the copper material of the pin is totally corroded.

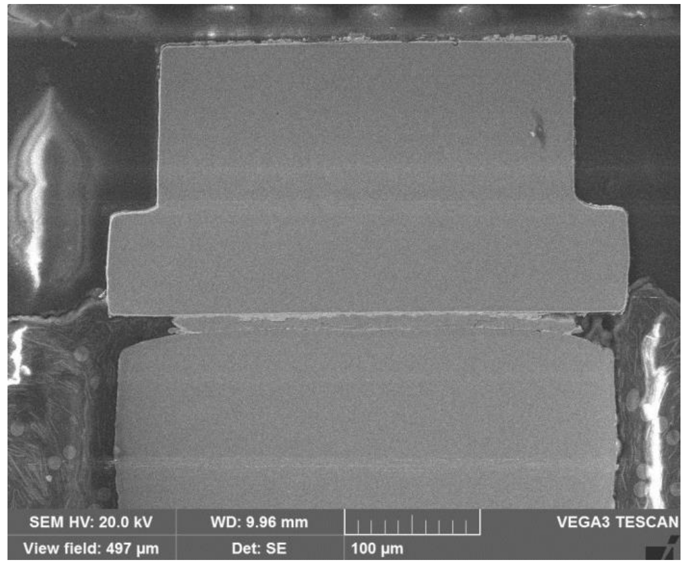

Figure 18: SEM image of a pin that was relatively unaffected.

Figure 19 captures the entirety of the pins from the new charger, sourced directly from the original manufacturer. Delving deeper, Figure 20 zooms in on one specific pin, magnifying its features and structure for a closer and more detailed examination. The high-resolution SEM imaging reveals the nuances, layers, and craftsmanship of this individual pin, serving as a representative sample for understanding the construction and design of all the pins.

Upon meticulous scrutiny of the pin visualized in Figure 21, it becomes evident that the foundational copper substrate, which forms the core of the pin, is not left exposed. Rather, it's intricately enveloped by a trio of protective coating layers. These layered coatings are designed with the primary intent of safeguarding the copper substrate against the rigors of corrosion, which could compromise its electrical conductivity, as well as the inevitable wear and tear resulting from regular use.

The identification of these three distinct coating layers elucidates the manufacturer's dedication to product longevity and performance. Each layer likely plays a specific role, whether it's to act as a primary barrier against environmental elements, to improve adhesion between layers, or to provide a smooth and tactile finish. Recognizing these layers offers valuable insights into the strategic design considerations and the rigorous quality standards employed by the original manufacturer to ensure the charger's durability and efficiency.

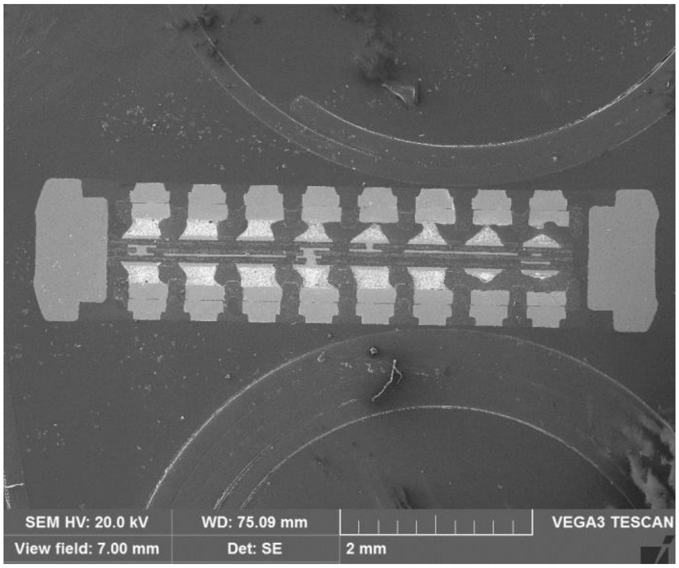

Figure 19: SEM image showing comprehensive visualization of all the pins from the new charger from the original manufacturer.

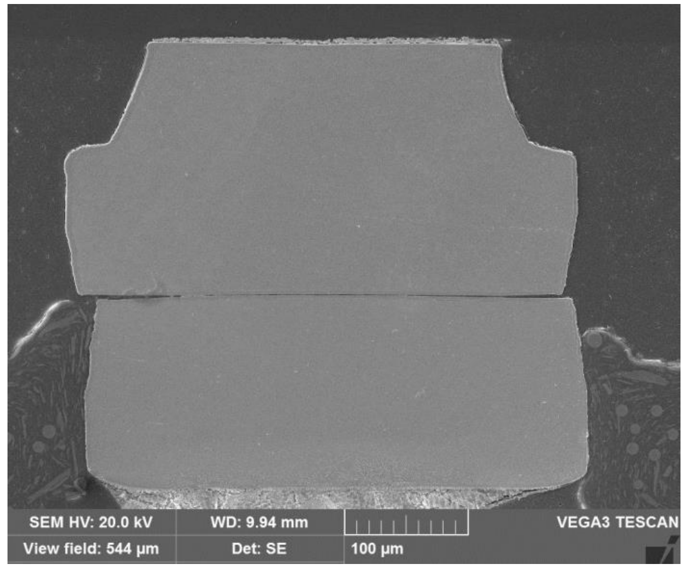

Figure 20: SEM image taken at one of the pins.

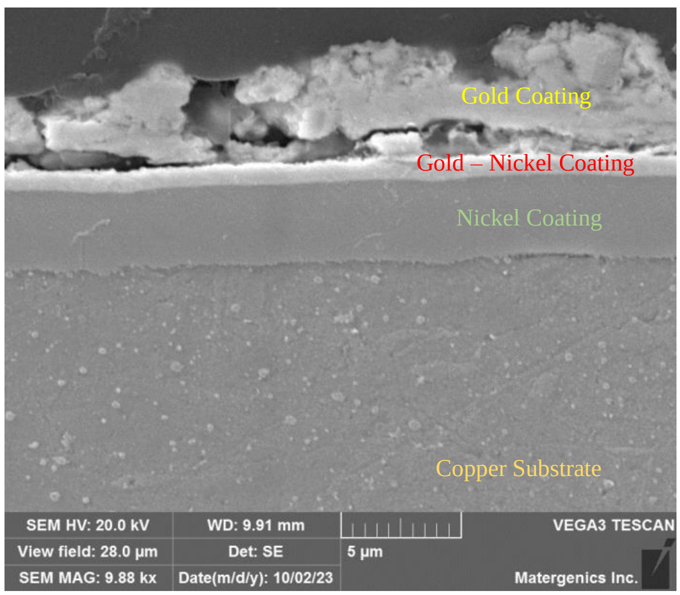

Figure 21: SEM image showing that the foundational copper substrate is intricately enveloped by a trio of protective coating layers.

Analogous SEM observations (Figures 22 – 24) were recorded for the charger sourced from an original manufacturer-approved third-party vendor, which was acquired from a nearby local store. This detailed SEM analysis showcased similarities, indicating that even though the charger was not directly from the original manufacturer, it adhered closely to the same rigorous standards and specifications.

By comparing the SEM imaging of both chargers, it was evident that the third-party vendor maintained a high level of consistency and quality in its product. The resemblance in the microscopic features suggests that the vendor, while perhaps employing its own manufacturing processes or materials, was diligent in aligning with the design and performance criteria set forth by the original manufacturer. This is particularly significant, given that the product was procured from a local store, demonstrating that even at the retail level, the quality and integrity of the product remained uncompromised.
Furthermore, this consistency in SEM findings underscores the effectiveness and reliability of the original manufacturer's approval system. By setting stringent criteria and ensuring third-party vendors adhere to

them, the manufacturer effectively extends its brand promise and product reliability to products not manufactured under its direct oversight.

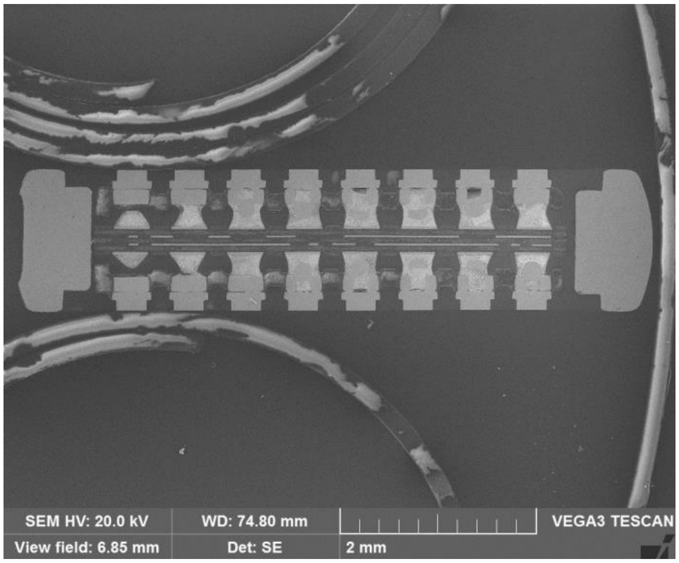

Figure 22: SEM image showing comprehensive visualization of all the pins from the new charger sourced from an original manufacturer approved third-party vendor, which was acquired from a nearby local store.

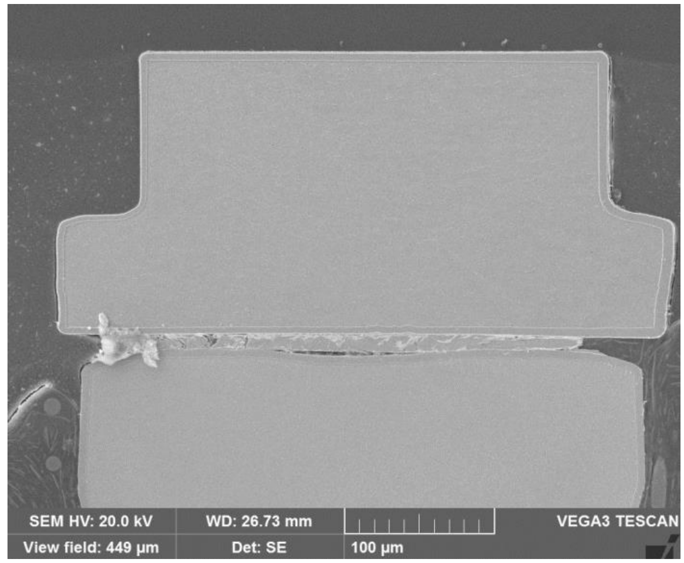

Figure 23: SEM image taken at one of the pins.

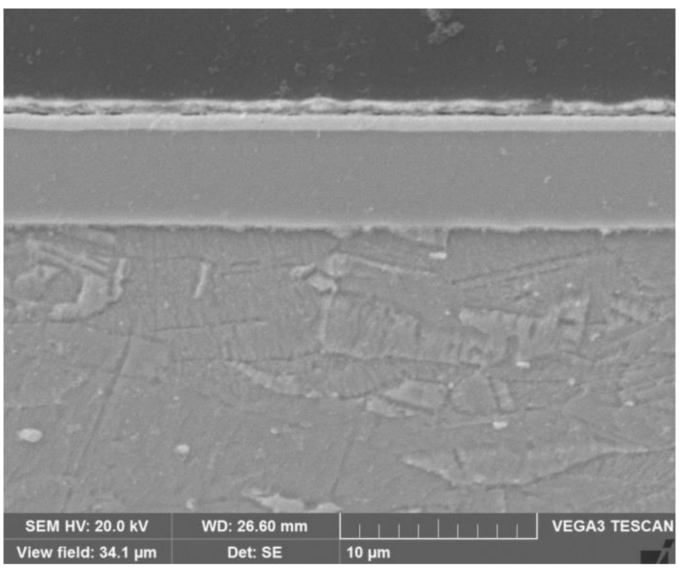

Figure 24: SEM image showing that the foundational copper substrate is intricately enveloped by a trio of protective coating layers.

Tables 4 through 13 present an exhaustive display of the EDS data, examining the three distinct chargers. Through this advanced analytical method, the elemental compositions of the charger coatings are brought to light, offering insights into the specific materials used in their manufacturing process.

A significant revelation from the EDS analysis is the identification of a platinum coating on one of the chargers, the new charger sourced from an original manufacturer approved third-party vendor, which was acquired from a nearby local store. Platinum, a noble metal like gold, offers excellent corrosion resistance and can serve as a robust protective barrier, ensuring the longevity and performance of the charger's pins.

Aside from this notable difference in the outermost coating material, the EDS data confirms that the remaining coatings and the underlying substrate materials align consistently with those of the original manufacturer's charger. This consistency suggests that while there might have been a strategic or cost-effective reason for opting for platinum over gold in the coating process, the core design principles and material choices remained largely unchanged, echoing the standards of the original manufacturer. Another potential explanation might be that subsequent chargers utilized a platinum coating in lieu of gold.

Element	Weight %	Atomic %
C K	8.55	48.62
O K	3.93	16.78
NiK	3.11	3.62
CuK	2.34	2.52
AuL	82.07	28.46

Table 4: EDS data taken at the gold-nickel coating on the relatively unaffected pin of the corroded charger.

Element	Weight %	Atomic %
C K	3.34	14.46
NiK	94.60	83.85
CuK	2.07	1.69

Table 5: EDS data taken at nickel coating on the relatively unaffected pin of the corroded charger.

Element	Weight %	Atomic %
C K	2.46	11.65
O K	0.29	1.03
NiK	2.47	2.39
CuK	94.78	84.92

Table 6: EDS data taken at the copper substrate on the relatively unaffected pin of the corroded charger.

Element	Weight %	Atomic %
O K	11.51	57.98
NiK	2.38	3.26
CuK	4.11	5.22
AuL	81.99	33.54

Table 7: EDS data taken at the gold-nickel coating on one of the pins of the charger from the original manufacturer.

Element	Weight %	Atomic %
C K	3.55	15.26
NiK	94.19	82.90
CuK	2.26	1.84

Table 8: EDS data taken at nickel coating on one of the pins of the charger from the original manufacturer.

Element	Weight %	Atomic %
C K	0.48	2.49
O K	0.11	0.42
NiK	5.41	5.69
CuK	94.00	91.41

Table 9: EDS data taken at the copper substrate on one of the pins of the charger from the original manufacturer.

Element	Weight %	Atomic %
O K	12.91	62.53
NiK	3.12	4.12
PtL	83.97	33.35

Table 10: EDS data taken at the platinum-nickel coating on one of the pins of the charger from the new charger sourced from an original manufacturer approved third-party vendor, which was acquired from a nearby local store.

Element	Weight %	Atomic %
NiK	100.00	100.00

Table 11: EDS data taken at nickel coating on one of the pins of the charger from the new charger sourced from an original manufacturer approved third-party vendor, which was acquired from a nearby local store.

Element	Weight %	Atomic %
C K	0.71	3.64
NiK	4.07	4.26
CuK	95.22	92.11

Table 12: EDS data taken at the copper substrate on one of the pins of the charger sourced from an original manufacturer approved third-party vendor, which was acquired from a nearby local store.

One of the paramount discoveries stemming from the EDS analysis pertains to the corroded pin's composition. The data indicates a pronounced concentration of both carbon and oxygen within certain deposits on the corroded pin. This elevated presence of carbon and oxygen suggests a noteworthy phenomenon. It raises the possibility of an electrical spark gap occurring between the phone charger pin and its corresponding mating pin on the phone.

The spark, due to its high temperature, could cause localized heating leading to the decomposition of any organic material present, producing carbon. Now, when such sparks are continuous or frequent, they can lead to degradation of the material. Over time, the constant high-temperature sparks cause wear and material loss. The carbon and oxygen-rich deposits can further act as sites for corrosion, especially in the presence of moisture, leading to accelerated degradation of the pin.

Table 13: EDS data taken on some of the deposits present at the corroded pin.

Element	Weight %	Atomic %
C K	78.79	83.45
O K	20.23	16.09
AlK	0.95	0.45
ClK	0.03	0.01

The observed phenomenon elucidates the pronounced corrosion on the fourth pin in contrast to its neighboring pins, despite them all facing ostensibly similar environmental conditions. Several interwoven factors contribute to this distinct corrosion pattern:

1. **Environmental Interplay**: All charger pins, including the fourth, are susceptible to interactions with external elements. Incidental contact with water droplets, perspiration from users, or ambient humidity can introduce potential corrosion agents. These elements, especially when combined, can act as catalysts for electrochemical reactions, initiating and accelerating the corrosion process.
2. **The Spark Gap Factor**: The fourth pin's specific susceptibility to the effects of spark gaps is of paramount importance. When spark gaps occur, they can lead to localized high-temperature events, producing micro-environments of rapid heating and subsequent cooling. This can result in material modifications, potential micro-cracks, and localized deposits, especially of carbon and oxygen.
3. **Unique Conditions**: Although all pins are subjected to a common environment, microscopic variances in conditions, coupled with unique vulnerabilities like spark gaps in the fourth pin, can lead to disproportionate wear and corrosion rates. These specific conditions make the fourth pin more vulnerable to degradation over time.

CONCLUSIONS

The extensive investigations into the three chargers, encompassing visual, stereoscopic, and microexaminations, as well as SEM/EDS data analyses, have unveiled distinct and noteworthy findings:

1. **Corrosion Disparity**: The fourth pin of one of the chargers exhibits significant corrosion compared to its neighboring pins. This pronounced corrosion, especially in an environment common to all pins, suggests localized factors at play.
2. **Material Composition**: EDS data revealed that while most chargers used gold as a coating, there was evidence of platinum being used in place of gold in some instances. The underlying material in corroded pins predominantly comprises a copper alloy.
3. **Coating Layers**: The SEM analysis highlighted that the copper substrate, pivotal for the pin's integrity, is protected by three distinct coating layers. Any breach or thinning of these coatings could expose the substrate to corrosive agents, making it susceptible to degradation.
4. **Environmental Triggers**: The consistent presence of electrolytes, such as water, sweat, and ambient humidity, was identified as a primary environmental catalyst for the corrosion processes. When combined with the specific vulnerabilities of certain pins, like the predisposition of the fourth pin to spark gaps, this leads to intensified corrosion.

5. **Spark Gap Effects**: The spark gaps occurring at specific pins can cause localized temperature fluctuations. This not only induces micro-cracks but also facilitates the deposition of carbon and oxygen-rich compounds, which act as catalysts for corrosion, especially in moisture-laden conditions.

RECOMMENDATIONS

1. **Improved Material Selection**:
    - Considering the susceptibility of the copper alloy to corrosion, particularly when its protective coatings are compromised, it might be prudent to consider alternative materials or alloys with enhanced corrosion-resistant properties.
    - While gold is a popular choice due to its conductivity and resistance to tarnish, the switch to platinum in some chargers suggests exploring other materials. It might be valuable to ascertain the long-term durability and cost-effectiveness of platinum in comparison to gold or potentially other metals/alloys.

2. **Enhanced Protective Coating**:
    - The three-layer coating, while effective to an extent, may need reinforcement. Consider the application of additional or thicker protective layers, especially focused on the fourth pin which seems more susceptible to degradation.
    - Investigate coatings designed to withstand high-temperature fluctuations, reducing the risk from spark gaps.

3. **Re-examine Charger Design**:
    - Given that the fourth pin exhibits a unique vulnerability to spark gaps and subsequent corrosion, it's crucial to re-examine its design and positioning. There might be an inherent design flaw that predisposes it to these vulnerabilities.

4. **Moisture Protection**:
    - Enhance the protective layers or introduce moisture-wicking materials to protect the pins from environmental factors such as sweat, humidity, and accidental water exposure.

5. **User Awareness and Handling Guidelines**:
    - Develop comprehensive user guidelines that emphasize the importance of keeping the charger and its pins dry and clean. Highlight potential risks associated with exposure to moisture, sweat, and other corrosive agents.
    - It might also be beneficial to offer tips on proper storage and maintenance to prolong the charger's lifespan.