Engineering and Technology Journal e-ISSN: 2456-3358

Volume 11 Issue 01 January-2026, Page No.-8655-8659

DOI: 10.47191/etj/v11i01.29, I.F. – 8.482

Analysis of the Root Causes of Particle Contamination in the Cathode Coating Process Using the Seven Tools Method at PT. XYZ

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ABSTRACT: Production quality is a key factor determining success in every industrial sector. To achieve these quality standards, PT. XYZ, a manufacturer of battery electric vehicles (BEVs) in Indonesia, implements a smart quality control system across its entire production line, from electrodes to formation. However, the production process involves many stages and has the potential for contamination by foreign particles. This study focuses on the cathode coating stage at PT. XYZ after copper (Cu) particles were found in electrode samples taken from the bobbin, guide roll, and top head areas.

Identification was carried out using EA-300 VHX and showed that the Cu particles had characteristics consistent with indications of contamination from machine components. These initial findings were then followed up by the company through a quality audit conducted in October 2025 to determine the source of the problem and assess the actual condition of the process. This study used the SMART approach and Seven Tools to analyze the causes of contamination and formulate applicable improvements.

The analysis results showed that contamination was influenced by suboptimal machine conditions, lack of cleanliness SOPs, and limitations of visual inspection in the smart quality control system. The recommended improvements focused on rearranging the coating parameters, strengthening the cleaning SOP, adding a vision camera to the unwinder, and performing regular maintenance on critical components. Through these improvements, it is hoped that the number of defects caused by particle contamination can be reduced to below the process tolerance limit and support continuous improvement in electrode production quality.

KEYWORDS: Cu Contamination, Coating Katoda, Smart Quality Control, Fishbone, Why-why Analysis, EV Battery

INTRODUCTION

As the electric vehicle market surges, electric vehicle (EV) battery manufacturers face a double challenge: meeting ever-increasing demand while maintaining strict quality standards. The electric vehicle battery industry is showing very positive growth trends.

Based on data from the IEA, demand for electric vehicle batteries will reach more than 1 TWh in 2024, an increase of around 25% compared to 2023. In 2024, the production capacity of electric vehicle batteries in the United States will reach approximately 200 GWh, while in Europe the capacity will be around 145 GWh. Meanwhile, Indonesia is just entering the early stages of the EV battery industry with a production capacity of around 10 GWh.

PT. XYZ uses NMC (Nickel-Manganese-Cobalt) as the main material in the cathode process, while the anode process combines graphite and copper. In the cathode process, the presence of foreign particles, especially metals such as copper (Cu), can reduce electrode quality because they can trigger corrosion, oxidation, and internal damage to the battery cell.

The issue of metal particle contamination remains a significant problem in the battery production process, especially in the electrode manufacturing stage. Although PT. XYZ has implemented a smart quality control system at a number of points in the process, in reality, micro defects caused by foreign particles still appear in the final stages of production.

This condition shows that quality control, especially in the cathode coating process, still has gaps that need to be improved. In the coating process, slurry stability, work area cleanliness, and the condition of machine components, including the unwinder, play a major role in forming a neat and contamination-free cathode layer. If metal particles such as copper (Cu) stick to the cathode surface, they can react with the cathode components, triggering corrosion and reducing the electrochemical performance of the cell. Even small defects can have a major impact on battery cell quality and can potentially cause failure during the formation stage.

Given the impact, a more in-depth study is needed to identify the points where contamination is likely to occur, evaluate the ability of smart quality control to detect micro-scale particles, and reassess the effectiveness of SOPs and machine conditions in the coating area. By understanding the root causes, it is hoped that more appropriate corrective measures can be implemented to maintain battery quality and enable PT. XYZ to remain competitive in the rapidly growing electric vehicle battery industry.

2. LITERATURE REVIEW

According to (Zhang et al., 2023), the global development of the electric vehicle (EV) industry demands improvements in battery quality, particularly in the cathode production process, which is a key component for battery performance and lifespan.

According to (Li & Wang, 2022), one of the critical issues that arises is Cu contamination on the electrode surface, which can reduce electrode efficiency and increase the risk of short circuits.

According to (Kim et al., 2021; Chen et al., 2020), previous studies have shown that these defects can originate from various factors, ranging from production environmental conditions, coating machine wear, inconsistent working methods, to operator errors and raw material quality.

According to (Ishikawa, 1982), several studies emphasize the importance of systematic root cause analysis, such as the application of fishbone diagrams, to map the factors that most influence defects.

According to (Singh & Patel, 2019), the Lean Six Sigma approach and the use of Seven QC Tools have proven effective in identifying and reducing production defects, including Cu defects.

This literature review emphasizes that a combination of environmental control, machine maintenance, standardized work procedures, operator training, and accurate inspection is the most effective strategy for reducing Cu defects in cathodes, thereby contributing significantly to the overall quality of EV batteries.

2.1. Flow Chart Process

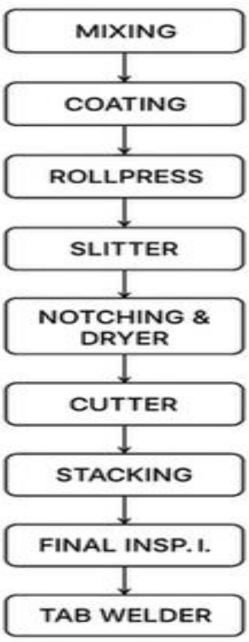


Figure 1. Flow charts process

2.2. Findings of Cu (copper) Contamination on the Electrode Surface

The examination was conducted using an EA-300 VHX digital microscope to observe the condition of the electrode surface at the coating stage. Samples were taken from the bobbin unwinder. From the observations, several spots with a brighter color and different texture from the surrounding material were found. This characteristic points to the presence of micro-sized copper (Cu) particles that could potentially adhere to the electrode surface.

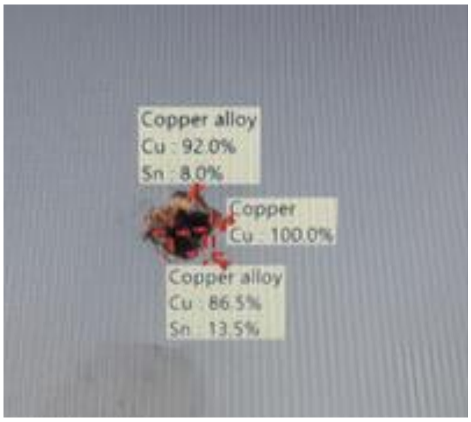


Figure 2. EA-300 Analysis

The results of EA-300 VHX observations on unwinder coating machine samples showing indications of Cu particles.

3. RESEARCH METHOD

The research methodology in this study is presented in Figure 3.

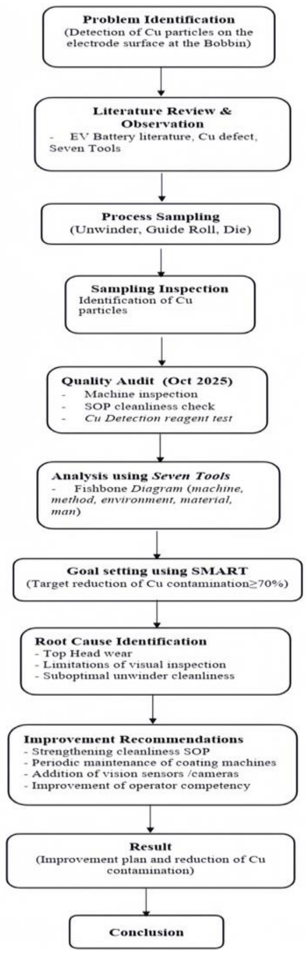


Figure 3. Research method

3.1. Analysis of Cu Contamination Sources

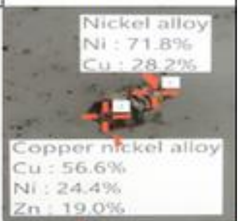
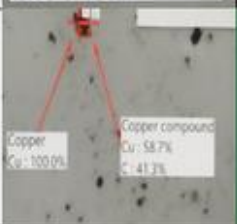
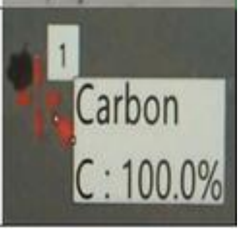
The study was conducted by taking samples from several points on the cathode coating area, namely the Bobbin Unwinder, Guide Roll, and Die. The samples were examined using EA-300 VHX to identify the types and characteristics of foreign particles. The presence of foreign particles at the coating stage can affect layer stability, increase the risk of oxidation, and ultimately reduce battery cell performance. To determine the potential sources, the process flow on the coating machine was analyzed thoroughly. Several points had the highest potential to be sources of contamination, namely:

1. The die section, which is highly critical and prone to component wear, allowing micro-fragments to be carried onto the foil surface.
2. The unwinder area, where the foil is first unwound, which has the potential to carry metal particles from the environment or friction with machine components.
3. The roller surface, especially if there are residues or wear that are not detected by routine inspections.
4. The environment surrounding the machine, including fine metal dust that is not captured by the filtration system.

This analysis shows that Cu contamination is not random, but has a pattern consistent with machine factors and visual inspections that are not yet fully optimal.

3.2 Sample Examination Results

Table 1. EA-300 Analysis

Area	Picture
Bobbin	
Guide Roll	
Top Head	

3.3 Quality Audit October 2025

The audit was conducted by the Quality Manager to verify the research findings and evaluate potential sources of Cu in machinery, production areas, and cleaning SOPs.

3.4. Analysis Using SMART and Seven Tools

To clarify the relationship between field findings and potential causes, analysis was performed using the SMART approach to set improvement goals and 7 QC Tools and why-why analysis to break down the problem in more detail.

(1) SMART Goals

The goals set focused on reducing Cu contamination in the coating process with the following characteristics:

Specific: Reduce the occurrence of Cu particles on the electrode surface.

Measurable: A minimum 20% reduction in the number of findings within a 12-month production period.

Achievable: Can be achieved through SOP improvements, increased inspections, and machine maintenance.

Relevant: Directly related to cell quality and rejection rates.

Time-based: Implementation is carried out within a 4-week timeframe.

(2) Use of Seven Tools

The analysis was conducted using a fishbone diagram. The results pointed to the high probability that the source was wear and tear on the top head components and the limitations of visual inspection.

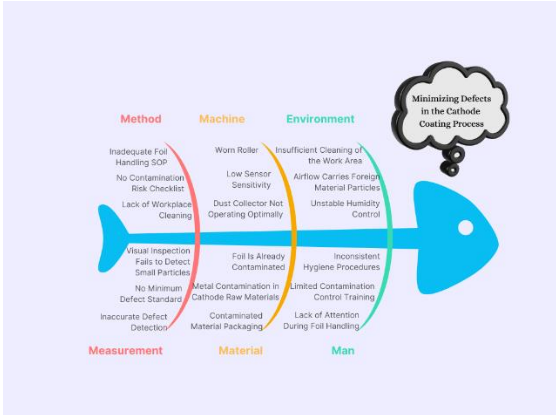


Figure 4. Fishbone Diagram

(3) Why-Why Analysis

• Why are there Cu particles on the surface of the cathode electrode?

Because Cu particles stick to the foil during the coating process.

• Why do Cu particles stick to the foil?

Because there is a source of metal particles from the web path that comes into contact with the foil, especially in the unwinder, roller, and areas near the die.

• Why do these areas produce Cu metal particles?

Because some components experience micro-friction or wear, producing small metal particle fragments.

• Why did this wear and micro-friction go undetected earlier?

Because monitoring of component cleanliness and condition was not fully effective, including cleaning critical areas, inspecting rollers, and checking die gaps.

• Why were monitoring and cleaning not effective?

Because the SOP did not specifically target areas prone to producing micro particles, routine inspections often missed areas susceptible to Cu contamination.

3.4 Root Cause

After comparing all findings and analyses, the root cause of the Cu particles can be concluded as follows:

1. Wear on the top head coating, potentially causing micro-fragments to adhere to the foil.
2. Limitations of the smart visual quality control system, which is unable to consistently detect micro-particles across the entire surface area.
3. Insufficient inspection and cleaning in the unwinder area, allowing small particles from the environment to be carried over before the coating process begins.

4. RESULTS AND DISCUSSION

Based on the results of the analysis at the cathode coating stage and the findings of copper (Cu) particle contamination identified through EA-300 VHX testing, improvements are needed to reduce the potential for defects. In addition, during the electrode quality audit conducted in October 2025, the company's Quality Manager conducted Cu detection reagent testing and found several control gaps that reinforced the need for corrective action in the coating process.

1. Strengthening Production Area Cleanliness Standards

The audit showed that the coating area is the most vulnerable to exposure to micro-particles. Therefore, cleanliness SOPs need to be tightened, including daily checks, increased cleaning frequency, and strict monitoring of airflow conditions. Operators are also required to ensure that work clothes remain clean.

2. Regular Maintenance of Coating Machines

The audit findings indicate potential wear on the top head and the area around the unwinder. Regular maintenance and scheduled inspections must be carried out to prevent the release of metal particles due to friction between machine components. Maintenance records also need to be improved so that any anomalies can be tracked and responded to more quickly.

3. Addition of Sensors and Particle Detection Systems

The limitations of visual inspection in smart quality control were highlighted in the audit. Therefore, the company needs to consider adding sensors and high-resolution vision cameras in the unwinder area and before the material enters the top head, so that foreign particles can be detected earlier.

4. Improving Operator Competence

The audit also noted the need to improve operators' understanding of particle-prone areas and the urgency of quick corrective action. A more in-depth technical training program is expected to improve operators' readiness to identify and handle anomalies.

5. Application of Seven Tools and SMART Method

To ensure that improvement recommendations are measurable, companies are advised to apply Seven Tools as the main analysis tool, while the SMART method is used to set clear, realistic, and easily evaluable goals. With this approach, the results of improvements will be more focused and can be measured periodically.

5. CONCLUSION

Based on a series of tests and analysis, it can be concluded that copper (Cu) particle contamination is one of the most critical defects that occur in the cathode coating process. The Cu particles found on the electrode surface were proven to originate from areas that come into direct contact with the foil, especially the unwinder, support roller, and components around the die gap.

The presence of these metal particles, despite their very small size, has the potential to cause local corrosion, electrochemical reaction instability, and increase the risk of short circuits in battery cells. These findings indicate that the quality of the coating process is greatly influenced by the mechanical condition of the machine, the cleanliness of the working environment, and the consistency of the slurry distribution during coating. Irregularities in any of these factors can trigger contamination.

Therefore, preventing Cu defects requires a comprehensive approach, not only through strict cleaning procedures, but also regular monitoring of machine components that are at risk of becoming sources of particles. Overall, this study confirms that strengthening cathode coating process control is an important step in maintaining electrode quality stability and reducing the potential for cell failure in subsequent stages. The implementation of appropriate improvements is expected to significantly reduce the level of Cu contamination and increase the reliability of electric vehicle battery production.

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Lack of Attention During Foil Handling