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Using Predictive Analytics Approaches to Investigate Climatic Reliability and Humidity Robustness issues of PCBA under Different Conditions

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Nowadays, climatic reliability and humidity robustness of electronic devices has become significant issue for both consumer and industrial electronics due to various reasons. One reason for this increased problem is the widespread use of electronics in many locations. The climatic reliability of electronics is attributed to the interaction of external climatic conditions and printed circuit board assembly (PCBA) characteristics as the main part of each electronic device, which compromise the performance of electronics due to the electrochemical failure process. In order to improve the reliability of electronics, requires a detailed understanding of the synergetic and interaction effects of various controllable factors, such as humidity, temperature, pitch distance, voltage, contamination types, and contamination levels. Moreover, it is crucial for reliability assessment to understand the relative importance of factors and their levels to take remedial action at an earlier stage based on selecting the best PCBA material, soldering process, and optimizing the design in desired tasks for particular applications and climatic conditions. This study presents the most suitable approach and prediction model based on the input datasets by using a combination of statistical analysis, probabilistic approaches, and machine learning algorithms to predict leakage current (LC), time to failure (TTF), failure state, and highly risky conditions, that could provide a better perspective of PCBA reliability and helps to reduce electronic waste due to failure.

Keywords: climatic reliability, PCBA characteristics, humidity robustness, predictive analytics, failure prediction models.

1. Introduction

The climatic reliability of electronic devices is determined by the complex interplay between external climatic conditions (extrinsic factors) and the characteristics of the printed circuit board assembly (PCBA), which constitute the intrinsic factors of electronic devices. These factors have the potential to compromise the performance of electronic devices due to the occurrence of electrochemical failure processes (Bahrebar 2022). Electronic components and systems (ECSs) used in various applications are subjected to diverse climatic conditions and must therefore be highly reliable and robust to operate under extreme circumstances. Climatic conditions can induce reliability issues in ECSs, resulting in intermittent or permanent failures. Many of these failures arise due to transient water film formation on the surfaces of PCBs or other assembly components exposed to varying climatic conditions (Ambat and Conseil-Gudla 2016). This triggers an electrochemical process between the biased points on the PCBA surface, resulting in a drop in surface insulation resistance and, eventually, an electric short circuit due to electrochemical migration (ECM) (Bahrebar and Ambat 2021), (Bahrebar and Ambat 2022). However, other corrosion failure modes are also possible depending on the materials and environmental conditions (Bahrebar et al. 2018), (Rastayesh et al. 2020). Therefore, it is crucial to focus on enhancing climatic reliability and developing preventive strategies to mitigate PCBA failure using predictive knowledge. Based on prediction methods, several preventive measures are possible, including extrinsic strategies such as using conformal coating as a barrier protection, or special enclosures to minimize the effect of climatic conditions (Conseil-Gudla 2017), and intrinsic strategies such as changing PCBA characteristics using different materials, designs, and soldering processes during production (Guene 2017).

2. Overall Discussion

In this investigation, we aimed to predict leakage currents (LCs) and time to failures (TTFs) due to ECM failure on PCB surfaces, as well as categorical failure states of different conditions. To achieve this, we employed a variety of predictive analytics approaches, including statistical, probabilistic, and machine learning models, using different datasets of laboratory test results (Bahrebar, Homayoun, and Ambat 2022). Overall, this investigation provides valuable insights into predicting ECM failures on PCB surfaces and can be used as a basis for improving the reliability and reducing the risk of failure in electronic systems (Bahrebar 2022). In terms of failure prediction, various methods were considered, including multivariate regression analysis, ANOVA, probability distribution analysis, common machine learning algorithms, and some combination of these methods. Furthermore, the correlation between PCB failures was presented, which is useful for predicting TTF before ECM happens. The general current behavior in three parts (stable part, transient part, as well as unstable part) was modeled as a sigmoid curve, and a logistic function was used to predict future changes.

3. Overall Conclusion

Our investigation revealed that humidity significantly influences both failure status prediction due to ECM and LC values. Humidity plays a significant role in climatic conditions by inducing the formation of a water layer on the surface of PCBs. This phenomenon is closely associated with contamination type effects, as the hygroscopic nature of the activators present in the flux ionic residue contributes to the overall influence. The combined impact of these two factors accounts for more than 70% of the observed effect on the failure status. Moreover, machine learning algorithms offer several advantages over other methods for predicting failure stauts and LC values. In particular, machine learning algorithms provide more profound insights with remarkable accuracy, and they can handle big data with good speed. These algorithms can map nonlinear relationships and perform well with messy data that may contain outliers and missing values. Additionally, machine learning algorithms can visualize multiple and complex interactions, especially tree-based algorithms.

Among the most common machine learning algorithms for both classification and regression analysis in our study, the RF (random forest) algorithm showed the most well-organized performance on the training dataset. We evaluated the RF algorithm using appropriate metrics on the validating dataset and found that it performed well in predicting PCB failures as the most suitable classifier and regressor model. Accordingly, we recommend the RF algorithm for predicting PCB failures. Fig. 1 presented the evaluation of classification accuracy using (a) the confusion matrix and (b) regression accuracy through the Kernel density estimate (KDE) plot of the RF.

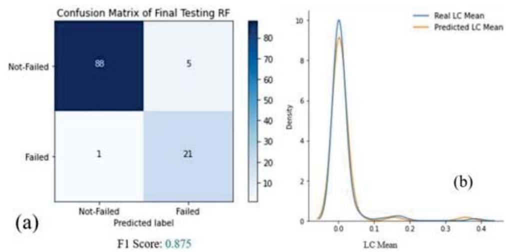

Fig. 1. Confusion matrices (a), and KDE plot (b) of RF algorithm on the test dataset.

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