

Algorithm for Ultrasonic Wire Bond Outlier Classification

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Abstract

Wedge bonders use ultrasonic energy to bond metal wires onto metal substrates in a process that takes milliseconds. In high-volume production, failures cause downtime and costs. On-line monitoring systems are used to reduce the failures and determine the root cause. We developed and tested an algorithm to classify outliers in ultrasonic wire bond production. The algorithm is used in large wire wedge bonders to measure and analyze process signals and detect and classify bond outliers. It helps bonder operators, production supervisors and process engineers to detect process deviations and fix the underlying root causes. The algorithm measures bond signals, such as deformation, ultrasonic current, and ultrasonic frequency. Bonds are automatically divided into subgroups based on bond order and process parameters, and the signals within a subgroup are then normalized. For outlier classification, the features are extracted from the normalized signals and combined into failure class values. The failure classes such as contamination, no wire, high deformation, misaligned wire, and unstable substrate, are calculated independently. We measured the detection rates for large wire aluminum bond failure classes and demonstrate how the algorithm calculates failure class values from the signals. Additionally, we show how new signal features and failure classes can be defined to detect production-specific or rare failure classes.

Key words

Wedge Bonder, Ultrasonic Wire Bonding, Outlier Classification, Bond Failures, Detection Algorithm.

I. Introduction

Wire bonding is an essential and known process for making interconnections between the wire and the substrate using an ultrasonic welding process. These interconnections are made on devices such MOSFETS, microcontrollers, and EV batteries. Good manufacturing practice aim to reduce and identify failures, especially during the bonding process. A single imperfection can mean the failure of the entire device. Identifying these failures in real-time can reduce downtime and as a result, increase productivity.

Wire bond traces are used to determine a stable process for set applications. They allow the process engineer to gain insight of their application by looking at wire bond traces such as deformation, ultrasonic current, and ultrasonic frequency during bonding, as shown in Figure 1. However, it takes an experienced operator to understand the quality of the wire bonds via these wire bond traces and with advances in wire bonding technology requiring higher reliability, bonding speed and product yield, new methods have been proposed to validate the quality of wire bonds in

real-time without the need of an experienced operator [1] Some of these methods include wire bond quality monitoring via system impedance, and with the use of x-ray tomography.

One of the quality monitoring methods, proposed in this article, is through the use of an outlier classification algorithm. A good set of bond traces are first created to allow the algorithm to learn the correct limits for a certain process. These limits are then used as a threshold that would indicate with a failure value if a bond trace is outside of these limits. Different failure classes can be identified with this method and have been studied in [2].

The objective of this article is to expand the outlier classification algorithm to accept user-based parameters to detect failures in their process for further failure analysis. An experiment is tested to verify if a wire bond with a short tail length failure can be classified correctly using a distinct set of parameters.

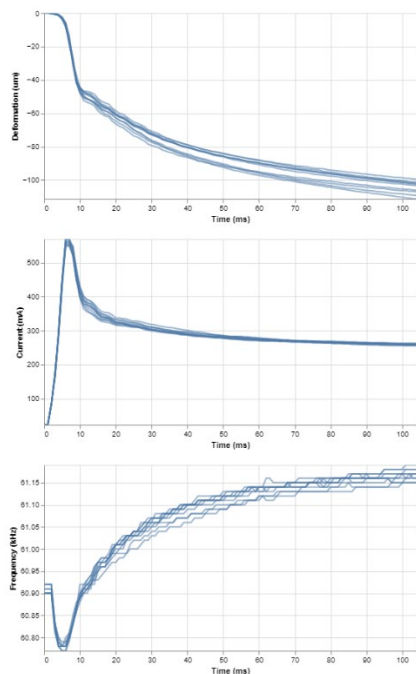


Fig. 1: Wire bond traces used to identify the quality of a wire bond and verify the stability of a process. Top to bottom: deformation (microns), ultrasonic current (mA), ultrasonic frequency (kHz).

II. Experiment

An Asterion ultrasonic wedge bonder was used from Kulicke & Soffa Industries. The wire size and type used in this experiment was a 300-micron 99.99% Al wire. The wires were bonded on an Al plate using a 60kHz ultrasonic transducer. Nominal bond parameters were used during training of the algorithm so that it can learn the correct set of limits for ultrasonic current, deformation, and ultrasonic frequency, as shown in Fig 2. A total of 100 single wire bonds were used during the training phase. In the test phase, ten single wire bonds were bonded with tail length settings of 1125, 800, 700, and 600 units, respectively.

Initial testing of the experiment showed that the algorithm could only detect the short tail length failure during extreme conditions, when the tail length setting was set to 600 units. The wire bond traces shown in Fig 3 indicate that the process for tail length settings of 800 and 700 units seem to be unchanged. The wire bonds, however, were of bad quality, seen in Fig 4. Further analysis of the short tail length failure was done, and a new set of failure parameters were created and loaded into the algorithm.

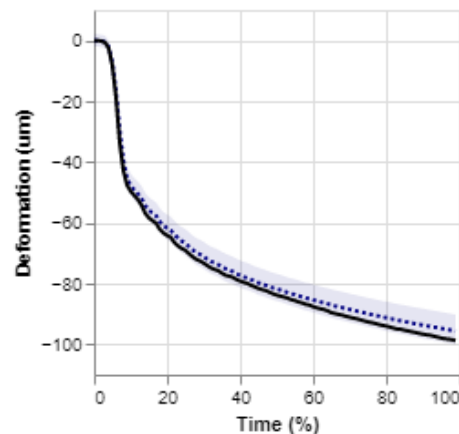


Fig 2: Example of learning the limits for a certain application. The shaded region indicates the upper and lower limits. The dashed line indicates the median values.

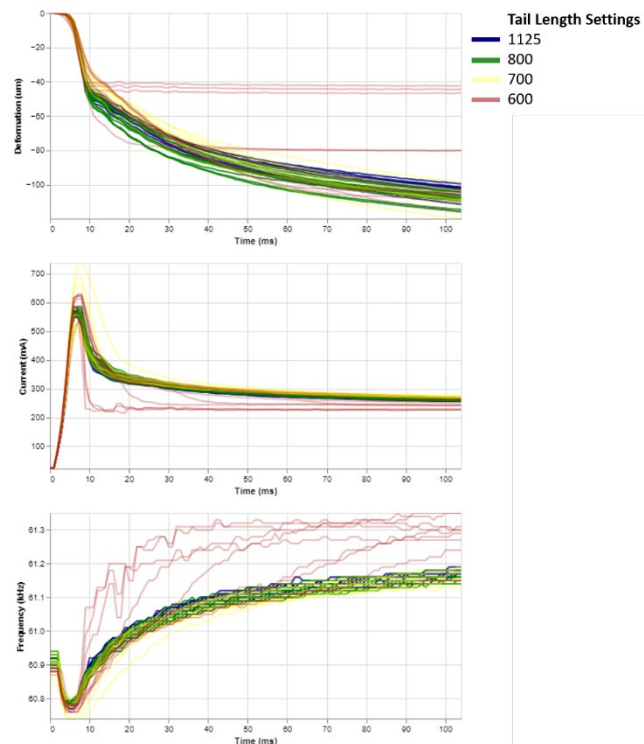


Fig 3: Wire bond traces of short tail length experiment with different short tail length settings. Tail length setting of 600 shows the result of the bond tool touching the surface. Tail length settings of 800 and 700 are of bad quality but their wire bond traces are similar to the good trace of tail length setting 1125.

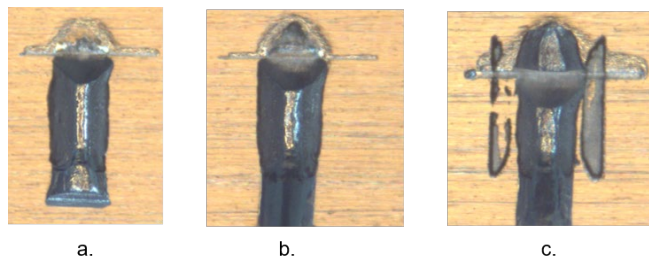


Fig 4: Wire bonds with different tail lengths: a) 800 microns b) 700 microns c) 600 microns. At 700 microns the cutter blade is seen to cut into the bond causing increased wear to the cutter and results in the wire to be of poor quality for the next bond. At 600 microns the bond tool begins to touch the surface due to the wire being stretched.

III. Results

The failure classification algorithm can accept user parameters to categorize a wide range of wire bond failures. In this experiment, the parameters were tuned to identify short tail length failures using the offline failure analysis tool. Wire bonds with short tail lengths are identified as bad quality bonds because it lowers the weldability of the wire for the next bond. Fig 5 shows a comparison of the wire underneath the bond tool between a properly cut wire and a wire with a short tail length. Upon initial testing of this experiment, the short tail length bonds were not classified as a failure and a new set of parameters were created using the offline failure analysis tool. After modifications, the failure classification algorithm flagged the bonds with a short tail length with a warning at a tail length setting of 800 and failures at a tail length setting of 600, seen in Fig 6. As a result, the failure classification algorithm proves to be adaptable and can be used as a failure study tool to further analyze a certain process using user-based parameters.

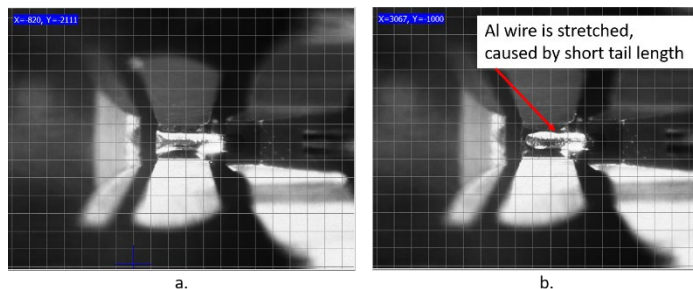


Fig 5: Bottom view images of the wire underneath the bond tool. a.) Proper seating of the wire after bonding using nominal tail length settings. b.) Bad wire quality caused by a short tail length setting.

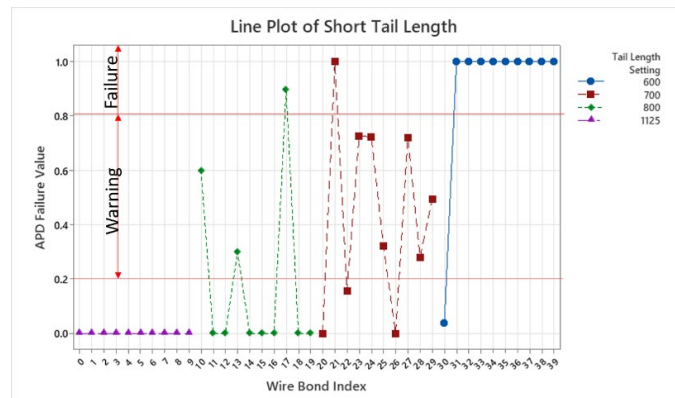


Fig 6: Algorithm Failure Values vs Wire Bond Index with different tail length settings. Wires were bonded in sets of ten using different tail length settings. The tail length settings were decreased to simulate a short tail and to verify the validity of the short tail length detection algorithm parameters. Short tail lengths are difficult to detect because the cut move is done after the wire has been bonded. This entails that a wire with a short tail length can still have a good bond trace. The algorithm can detect early signs of a bad quality bond and flag these as a warning. Over a period of multiple bonds, the wire underneath the bond tool will be of poor quality and it will affect the weldability of the wire. In the worst-case scenario, the bond quality and the bond traces become apparent and these are shown as failures.

IV. Offline Failure Analysis

The failure classification algorithm can accept custom classification parameters which makes it adaptable to any process. For this experiment, further analysis proved that the wire bonds for tail length settings of 800 and 700 units experienced end frequencies that varied from the normalized frequencies of the trained wire bonds. These bonds also showed a higher start current. A new failure criterion was defined using an offline tool that uses the failure classification algorithm with saved bond traces. This tool provides an environment to test and analyze different failures using previous wire bond trace data. Fig 7 describes how the failure classification is used in both real-time process monitoring and offline failure analysis. Table I shows how the tuned parameters can better detect warnings and failures during real-time bonding.

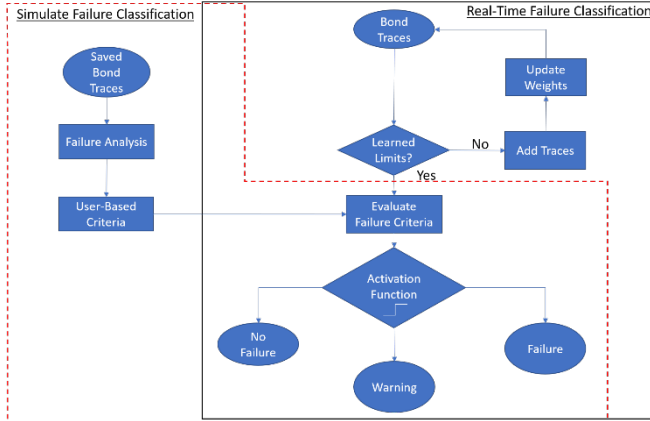


Fig 7: Failure classification algorithm flow chart for real-time process monitoring and offline failure analysis.

Table I: Short Tail Length Failure Detection

	Tail Length Setting	Good	Warning	Failure
Original Failure Classification	1125	10	0	0
	800	10	0	0
	700	10	0	0
	600	5	0	5
Tuned Failure Classification	1125	10	0	0
	800	7	3	0
	700	2	7	1
	600	1	0	9

V. Conclusion

A process diagnostic tool is presented that uses a failure classification algorithm to detect failures in real-time during the wire bonding process. The tool is adaptable to take in user parameters and offers an offline environment to test different failure classifications using saved wire bond trace data. The results indicate that the failure classification parameters can be fine-tuned in the offline environment and used in real-time bonding to flag the failed wire bonds.

This diagnostic tool is part of the Advanced Process Diagnostics (APD) feature in Kulicke & Soffa wedge bonders.

References

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- [2] Seppänen, Henri, Chua, Siang Tat, Martinez, Joel Elizondo, Villa, Pedro, "Ultrasonic Wire Bond Outlier Classification", 2021