The Use of Failure Analysis as a Preventative Quality Tool

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The materials and processes used to fabricate electronic components have significant effects on their ultimate reliability. By examining a small number of samples, high risk types of materials and poor workmanship can be flagged, either excluding them from production use, or using them to drive corrective actions. The tools of failure analysis are well suited to this approach, even though the sample components have technically not failed at all. Both nondestructive and destructive types of analysis can be used. By focusing on comparative device analysis between available suppliers, it is possible to find the best in class components for use in high-reliability applications such as automotive electronic modules.

Keywords
electronic component failure, failure analysis, quality control

1. Introduction

USERS of electronic components have several choices available to ensure the quality and reliability of purchased piece parts. To assess an unknown device so that early decisions can be made about possible risks before use in a new design, some type of qualification process typically is used. This process may involve a number of different disciplines, including reliability testing, reviews of supplier test data, supplier quality system audits, first article inspections, and production line trials.

Before proceeding with these activities, an early, fast approach to the materials analysis of qualification samples has been developed. To improve on the preventive opportunities of the existing qualification process even more, the supplier may be asked to provide the construction analysis, and one step further up the supply chain, similar information in turn may be required from his raw material suppliers. The end result of this approach is faster risk assessment for new devices and better understanding of expected performance, on a materials level, than has been traditionally possible by other means of evaluation, such as testing, inspection, or quality surveys.

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2. Reliability and Construction

The automotive industry is making more use of electronics every year for engine and brake control, pollution sensing, displays, and a growing list of other functions. Each of these functions typically requires use of a wide range of electronic parts, of widely differing construction. The thermal stresses and corrosion opportunities within these products are clearly very high. Yet they must be built in the most economical way possible to remain competitive.

Each type of component has characteristic failure mechanisms that may be largely avoided by proper materials design and fabrication. A summary of some of the better known weaknesses and the environments that may simulate them to failure is shown in Table 1. A selection of several different types of components has been tabulated to illustrate the variety of potential problems that may be encountered. Most may be addressed with the same basic analytical techniques of microscopy and radiography, with suitable sample preparation. The intent here will be to show how these techniques can be applied in a program of early reliability risk assessment. The scope of this article does not allow a discussion of the details involved in analysis of all of the component types used in a typical product; references to supplemental works may be found at the end of the text.

The concept of construction analysis, or destructive physical analysis (DPA), is not new, having been used in specific contracts for electronic materials for some time. For military-

Table 1 Materials and assembly weaknesses and environments that can stimulate component failure

Device type	Construction weakness	Failure mode	Risk environment
Capacitor, ceramic	Dielectric crack	Leakage, shorts	Thermal shock
Capacitor, film	Internal contaminants	Leakage	Initial use
Capacitor, tantalum	Poor lead attachment	Open	Thermal cycle
Diode, axial	Excessive solder	Shorts	Power/thermal cycle
Inductor, wire wound	Poor winding protection	Shorts	Thermal cycle, humidity
Integrated circuit	Package voids	Corrosion	Humidity
	Wirebond sweep	Shorts	Thermal cycle
	Passivation defects	Corrosion	Humidity
Resistor, thick film	Excessive laser trim	High resistance	Thermal cycle
Resistor, wire wound	Winding terminations	Open	Thermal cycle
Transistor, power	Die attach voids	Catastrophic	Power/thermal cycle
Transistor, various	Improper wire bonds	Opens, shorts	Thermal cycle

grade integrated circuits, MIL-STD-883C, Method 5009.1, defines a DPA procedure for purposes of determining conformance to the applicable requirements. Many of the elements of this document are very applicable to commercial parts. The present approach, however, is less of an inspection for conformance than a common sense exam for any questionable materials or assembly practices. It is legitimate to raise any logical question with a supplier to resolve a potential risk. The process is tempered with experience in looking at a variety of parts from different suppliers.

Reliability testing, although requiring much more time than a construction analysis, is ultimately the best way to verify the predicted reliability performance of a given component. It has been found that, in cases where a risk is predicted by early construction analysis, failures very often do develop in subsequent reliability testing. Conversely, when failures have resulted in reliability testing that was not flagged in the construction exam, this history needs to be reviewed to continuously update the content of the construction analysis. These tasks are readily guided with standard forms or checklists for a given type of device and package.

3. Analysis Flow

Whether done by the component user or supplier, a typical construction analysis involves the steps shown in Fig. 1. An external examination under a low-power stereomicroscope is done first. Note that this is not an incoming inspection, but an early preventive analysis on several samples. Even an observation as simple as visual differences between the appearance of the samples may suggest process variances that should be questioned.

Nondestructive tools are then used to image some of the internal features of the samples. Radiography may reveal unusual leadframe designs, or potential shorts between bond wires in integrated circuits. Foreign materials may also be observed with this technique. Images of the samples with a laser acoustic microscope may reveal internal flaws such as voids in encapsulants, delamination between stacked layers of material (Fig. 2a), or more catastrophic defects such as cracks or bubbles. So far, the analysis has taken only a few minutes and has been nondestructive. Two destructive approaches are then available, which may vary somewhat depending on the component technology. Traditional cross-sectioning techniques can be very revealing of attachment integrity between materials. Figure 2(b) shows the location of the chip capacitor void identified with acoustic microscopy.

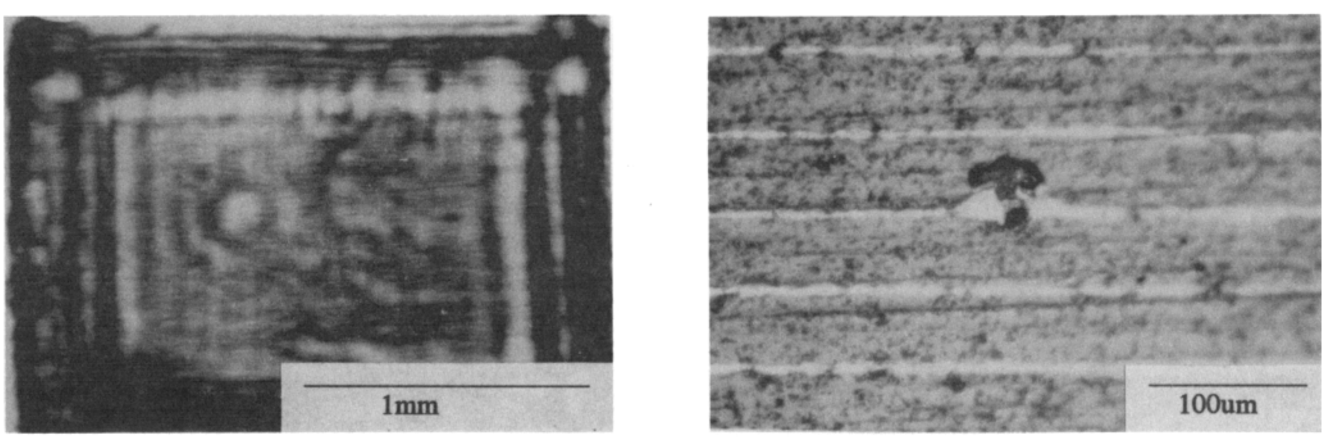
An example of serious voiding in a power single in-line package solder attach system is shown in Fig. 3(a). Gold wire bonds can also be observed here. A cross-sectional view (Fig. 3b) confirms the extent of voiding between the header and silicon die in this same sample.

For semiconductors and many types of passive components, chemical or mechanical decapsulation also can be used. Workmanship defects in wire bonding can result in an open pin (Fig.

External exam (10-30X)
|
Non-destructive imaging
|
- X-ray
|
- Acoustic microscopy
|
Internal analysis
|

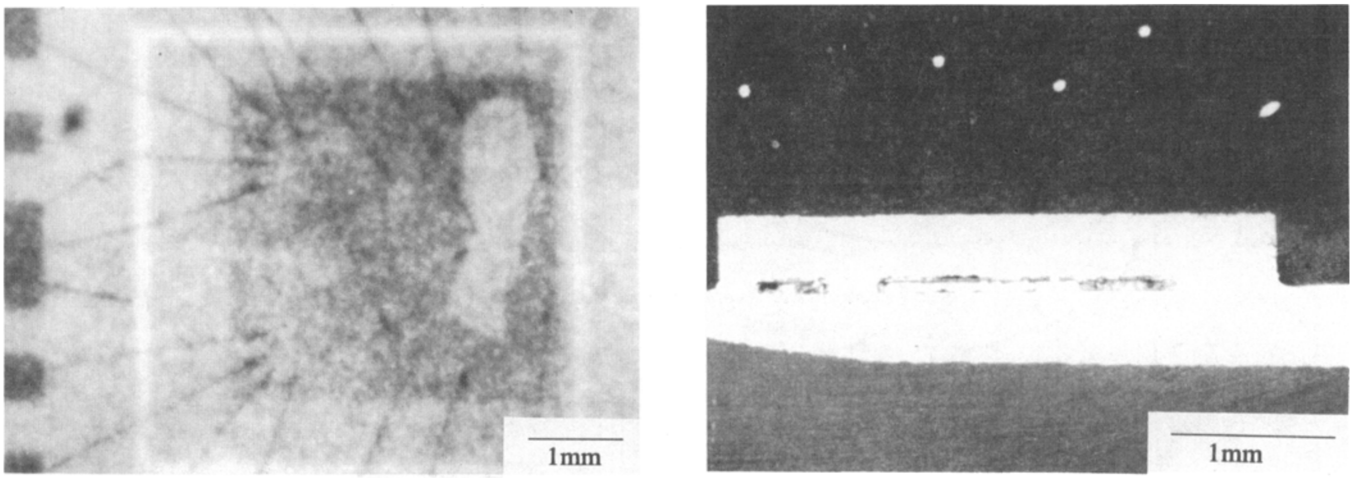
Decapsulate	Cross section
- Wire bonding	- Package voids
- Internal platings	- Die attachment
- Passivation coverage	- Die placement
- etc.	- etc.

Fig. 1 General construction analysis flow for an integrated circuit.



(a) (b)

Fig. 2 (a) Acoustic micrograph of ceramic chip capacitor. (b) Cross section of same component showing defect between dielectric layers.



(a) (b)

Fig. 3 (a) X-ray photograph of power device, showing location of underlying solder die attach and wire bond configuration. (b) Cross section of same device.

Table 2 Automotive component reliability

Typical test requirements for power transistor. Sample preparation and electrical measurements not included in test time.

Biased humidity	85% RH, 85 °C	1000 h
High temperature	150 °C	1000 h
Pressure, temperature, humidity	100% RH, 120 °C, 202 kPa,	96 h
Thermal shock (air to air)	–40 to +150 °C	1000 cycles
Thermal shock (liquid to liquid)	–40 to +150 °C	500 cycles

4) after the stress of a few thermal cycles. Additionally, in this sample, very little confidence could be inferred to the supplier's assembly operation, because a reworked bond remained and had been bonded over. In other cases, a bond misplaced on its bond pad can manifest as a latent short. Passivation problems, and more specific silicon-level defects such as oxide step coverage, also can be evaluated on the decapsulated device.

If no defects are found at this stage, the devices may still need to be tested for reliability. If problems are observed, which historically have been found in about 10% of devices analyzed in the author's laboratory, immediate correspondence with the supplier can be initiated regarding the need for corrective action. In any case, the construction data are documented and filed for future reference. The data have proven valuable in issues where a process or assembly location change has taken place and in a variety of other cases, in which reference to the internal construction of a qualified device was needed.

4. Qualification Cycle Time

As a new design takes shape, review of its constituent bill of materials will identify those components that are new and require evaluation. A critical path in the qualification process then involves obtaining samples from an intended supplier or suppliers and subjecting them to suitable reliability challenges (Table 2). Because this process involves initial electrical testing, up to 1000 h of test time in various environmental chambers, and final electrical testing, the overall cycle is too long for many of the current fast-moving programs.

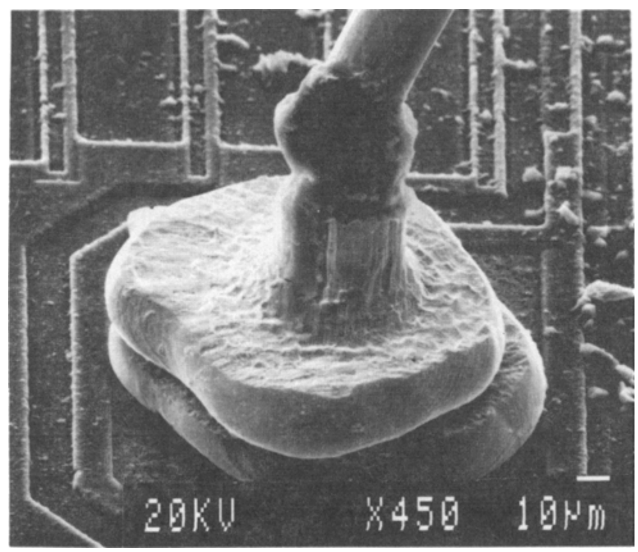


Fig. 4 Wire bond misformed after second bond was attempted, found in sample of five units. This is an obvious reliability risk.

One solution to the test time traditionally required is to develop accelerated tests, which must be correlated with the standard test environments. Even if this is possible, construction analysis of the device should still be the first step. Only after acceptable materials and construction are verified will the samples be continued through the reliability test program. This approach has resulted in earlier detection of reliability problems and savings in terms of wasted test hours. Samples that are unacceptable or at least questionable are reviewed before committing to a lengthy series of reliability tests.

In some cases, early construction analysis has determined that a supplier has submitted wrong parts, mixed construction,

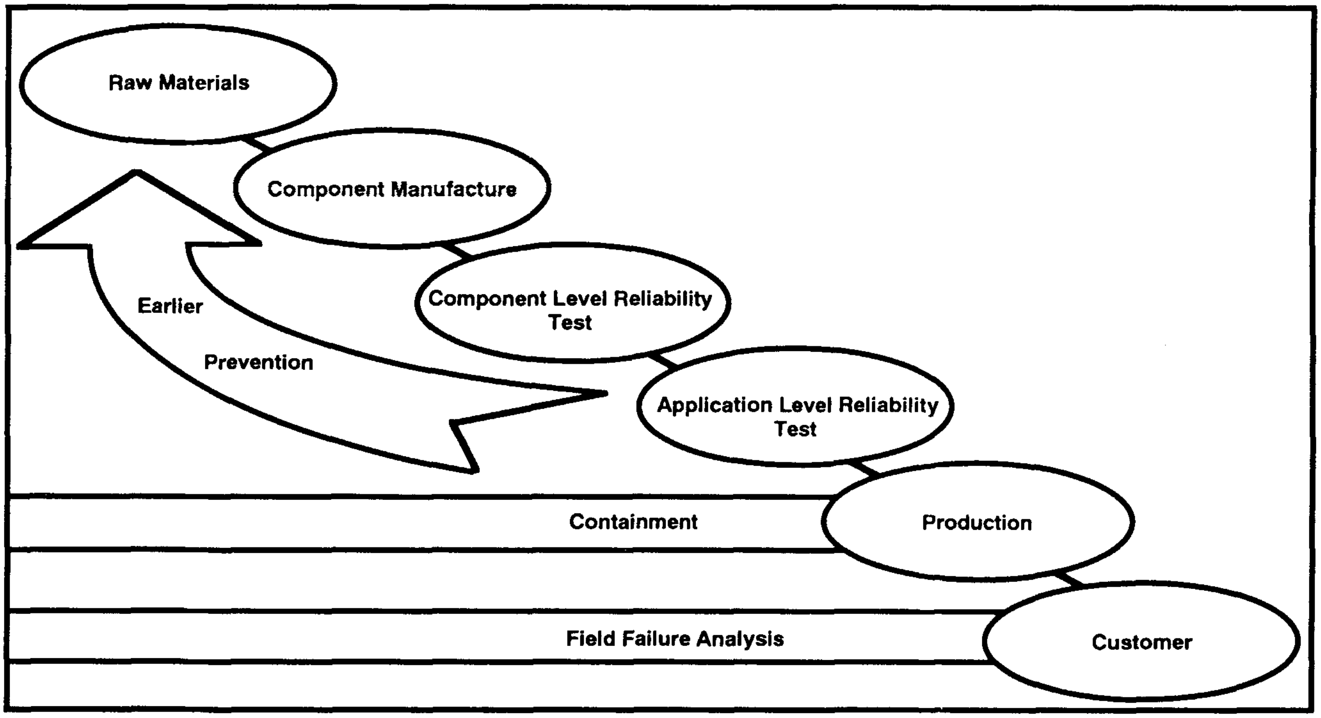


Fig. 5 Applying failure analysis earlier in the supply chain.

or early prototypes. In other instances, inconsistent assembly practices, unusual materials or platings, or designs that differ significantly from other like devices have been identified. In all of these cases, early identification of potential risks with the devices was made possible well before production has begun.

There are ways to move the qualification activity even further back to the prevention side (Fig. 5). This requires the supplier to provide the information with, or instead of, sample submission. By becoming familiar with a variety of different types of components and their typical materials and assembly techniques, the purchaser having performed construction analysis is in a good position to evaluate and challenge the construction data supplied. Any potential concerns can then be addressed even before samples are received.

Pertinent questions also can be asked of the supplier regarding the critical incoming materials used in manufacturing the device. Items such as material purity specifications, physical, and mechanical properties can then be reviewed for very early involvement with a potential supplier. A survey that evaluates suppliers' analytical capabilities, instrumentation, and degree of laboratory personnel skill and experience also can be revealing. All the data can be used in the earliest possible prediction of the likelihood of success with the component in question.

5. Prevention and Continuous Improvement

Where does all this fit into the analysis laboratories' other activities? This may depend on the type of business and quality approach a given company takes. In organizations where the quality system is developing, there may be no systematic approach to failure analysis at all. In a certified quality system, such as one conforming to international quality system standards such as the ISO-9000 series, failure analysis is still not specified as a requirement. For companies pursuing still more challenging goals, however, such as the Malcolm Baldridge National Quality Award, there may have to be considerable use of failure analysis as a quality improvement tool.

Of course, failure analysis still should be performed on actual failures, either from production fallout or from field use. To gain long-term improvements in the field failure rate, however, more preventive use of failure analysis must be pursued.

There are several areas where failure analysis can be used during either design work or ongoing production. In an early validation of a design's reliability, an analysis at the component level is useful to understand if a design weakness or a faulty component has resulted in failure. Appropriate corrective actions can then be pointed in the right direction. In a designed experiment, use of selected failure analysis tools can reveal underlying materials problems that might otherwise not be noticed.

When there is production fallout, component users need to categorize their quality data, which will require component level analysis. Knowing the cause of a device defect may allow better assessment of any possible risks to the customer and make it possible to start developing short-term containment screens and long-term improvements. Finally, the technical content that analysis can provide is a good partner to other problem-solving approaches, such as statistical methods and team-oriented activities. All of these types of work still constitute prevention, because they protect the customer from defects.

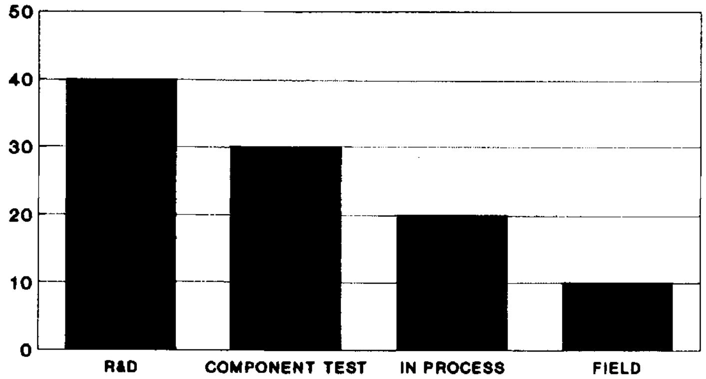


Fig. 6 Failure analysis origins—focusing on early prevention.

Figure 6 shows how the up-front use of failure analysis can be used effectively, the earlier the better, even before failures have developed, as has been argued here. In fact, Fig. 6 substantially depicts where failure analysis requests to the author's laboratory originate today. It could only be argued that the field return rate should be zero, which is the ultimate goal of total customer satisfaction. Given the influx of new products and component technologies, receipt of zero field failures may not be realizable, and there is evidence to indicate that even the best suppliers in the world are doing some field failure analysis. Their preventive activities are certainly critical to their success today and their competitive edge for tomorrow.

6. Conclusion

The analysis of small samples of new components, prior to performing further lengthy reliability evaluation, has been demonstrated to find defects early. Some examples of potential risks found with this approach are summarized in Table 3. If one compares the defects with the known risks shown above in Table 1, good correlation is apparent.

It is also possible to request that the component supplier perform the construction analysis and reliability testing and provide the data for review. Many high-volume users of components take this approach. By requesting the data required from the supplier, and testing and analyzing selectively, an effective mix of control points can be realized. The materials-based data collected are valuable additions to other more general business approaches to supplier relations.

Table 3 Examples of observed reliability risks: all were identified by nondestructive analysis

Defect	Analysis technique
Inconsistent or mixed parts	Light microscopy
Package voids	Acoustic microscopy
Die attach voids	X-ray, acoustic microscopy
Delamination	Acoustic microscopy
Wire bond sweep	X-ray
Wire bond touching die	X-ray
Foreign material	X-ray
Unique or known risk construction	Light microscopy, X-ray

In some respects, this is, and always will be, a learning process and a challenge to remain capable of understanding more complex component technologies.

Fortunately, instrumentation is improving as well, with the availability of confocal optical microscopes, acoustic microscopes, and improved real-time X-ray imaging. It has been found that suppliers who themselves possess good instrumentation and analysis skills are the best to work with. The move to more front-end supplier relationships is increasing the understanding between component suppliers and their customers, a trend which without doubt will continue well into the next century.

Acknowledgments

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