How to succeed in accelerated testing

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Recent years have seen product development evolve into an increasingly fast-paced process that has a greatly abbreviated product life cycle. Today we take for granted accelerated testing to compress the product testing period. However, unless accelerated testing is performed in accordance with test objectives, whether to detect design flaws, to detect defects that appear in the field, or to accurately grasp (predict) product life, such testing is meaningless.

The current trend is for persons in charge of product design and development to also be in charge of designing and running accelerated tests. In some cases this has led to unanticipated problems.

This report shall look at accelerated testing with a focus on environmental stress, and shall also present some real world examples of the type of problems and failures by which the tester, especially one with limited experience, can easily be tripped up.

The contents of this report are based on the presentation given at the Kansai Electronic Industry Development Center 2004 Reliability Seminar in Japan “The current state, with examples, of accelerated testing methods for evaluating the reliability of electronic parts”.

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1 Success and failures: Examples of accelerated testing

1.1 Successes

1.1.1 Dew Condensation Cycle Test – Ion migration accelerated method

Fig.1 The necessity of confirming the reliability of insulation with degradation from dew condensation

Along with the increased popularity of portable electronics has come the realization that it is crucial to maintain reliability by evaluating the degradation of insulation resulting from dew condensation. Product miniaturization combined with high-density mounting has resulted in increasingly minute spacing between conductors on circuit boards. This micro-spacing creates a high possibility that phenomena such as migration, which have not been an issue in the past, will emerge as problems. Even precipitates that have been too small to cause trouble may be able to interfere with device functions and produce defects. As products become smaller and lighter, they are put to an increasingly diverse range of uses. We must assume that products will be used in environments that would have been unthinkable in the past. Societal change has also affected reliability testing. The product liability law, enacted to represent the consumer’s point of view, has now been put into effect, making the manufacturer’s responsibility much more serious.
The Dew Condensation Cycle Test
The Dew Condensation Cycle Test is a test method that relies on abrupt changes in conditions that consist of precisely controlled high temperature and humidity to repeatedly create and dry uniform quantities of dew condensation in uniform periods of time. This cycle forces accelerated progression of degradation phenomena and leads to failure. When the temperature and humidity inside the chamber are abruptly raised, a large temperature gap is created. This gap results from the air temperature rising much more quickly than the temperature of the specimens, which have a much greater heat capacity than the ambient atmosphere. In these conditions, the temperature of the specimens reaches dew point, the dew begins to evaporate, and then attains equilibrium upon reaching the wet-bulb temperature. Then, when the specimen temperature is the same as the dry-bulb temperature, the dew condensation evaporates completely and the conditions become dry. This test relies on very precise conditions of temperature and humidity, with the specimens repeatedly alternating between a low-temperature atmosphere and a high-temperature, high-humidity atmosphere. These conditions cause accelerated progression of various degradation phenomena that are caused by dew condensation. One of the major phenomena investigated by this test is the degradation of insulation resistance.

Fig. 2 The Dew Condensation Test and the “dew condensation” $\rightarrow$ dry” process
(1) When the temperature and humidity inside the chamber are abruptly raised, the large gap in heat capacity between the air and the specimens causes the temperature to rise more slowly in the specimens, creating a temperature gap that produces dew condensation.
(2) When the dew-point temperature is reached, the dew condensation begins to evaporate.
(3) At the wet-bulb temperature, equilibrium is achieved.
(4) When the dry-bulb temperature is reached (during the high-temp., high humidity stage), the dew condensation completely evaporates from the surface of the specimens, yielding dry conditions.

Through repeatedly alternating between low-temperature conditions and high-temperature, high-humidity
conditions, this test is able to repeatedly reproduce “dew condensation” and “dry” conditions.

Main phenomenon produced by the Dew Condensation Cycle Test
The main phenomenon produced by the Dew Condensation Cycle Test is ion migration. In migration, metal ions are dissolved in the dew condensation moisture occurring on the electrodes, and these ions are reduced or precipitate out as compounds either as dendrites or as CAF (conductive anodic filaments) in one type of corrosion phenomenon. (Refer to Fig.3.)

(a) Dendrite
(b) CAF (Conductive anodic filaments)

Fig. 3 Examples of migration reproduced with the Dew Condensation Test

Evaluation method with the Dew Condensation Cycle Test
When running the Dew Condensation Cycle Test, one must grasp the characteristics of the insulation resistance that degrades as a result of environmental stress. The following three methods can be considered pertinent when evaluating the degradation of insulation resistance.
(a) Checking specimens under operating conditions
This method consists in checking for malfunctions while operating the specimen. This method is very easy to employ, but since there is a possibility of destroying the specimen
itself when applying power, this method entails a high degree of risk, and it may not be possible to analyze the factors leading to malfunction.

(b) Checking visually

This method consists in using a microscope to visually observe such phenomena as the dendrites resulting from the stress produced by the dew condensation cycles. The likelihood of destroying the specimen is slight, but observation must be carried out following a pre-determined number of exposure cycles, and so this method requires a lot of test time and a large number of specimens. The observation consists in confirming minute phenomena at high resolution, and so involves a lot of time to determine the characteristics of the phenomena and the areas in which they occur.

(c) Measuring insulation resistance

This method involves checking the insulation resistance while running the Dew Condensation Cycle Test. The test is not stopped while checking specimen condition, and so this test may be considered extremely rational and efficient. However, the test demands a high degree of technical know-how. The use of a high-resistance, multi-channel, high-speed measuring system can provide an effective reliability test for insulation resistance degradation.

Here at Espec, we are working to clear up these problems, and we develop both test equipment and the related measuring equipment. Fig.4 presents an example.

Fig.4 Sample block diagram of insulation resistance evaluation system
1.1.2 Combined Environment Test (high temperature + vibration)

The Combined Environment Test which simultaneously applies the two environmental factors of temperature and vibration is considered an effective test method for evaluating the bonding of solder joints. We shall present a real-world example.

The Combined Environment Test is a test method combining various forms of environmental stress. The example we shall introduce here combines stress from vibration to a temperature environment. We used QFP (quad flat packages) mounted on PCB (printed circuit boards) using lead-free solder, resulting in four different combinations of plating and solder. For comparison, we ran the High Temperature Test and the Vibration Test separately and compared the results of those tests with the results of the Combined Environment Test (temperature + vibration).

<table>
<thead>
<tr>
<th>Joint materials</th>
<th>QFP, Cu lead (0.5mm pitch)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface plating of parts</strong></td>
<td>-Sn·10Pb (Conventional solder)</td>
</tr>
<tr>
<td></td>
<td>- Au/Pd/Ni (Lead-free solder)</td>
</tr>
<tr>
<td><strong>Lead-free solder for joints</strong></td>
<td>-Sn·3Ag·0.5Cu (high reliability, good compatibility of conventional solder)</td>
</tr>
<tr>
<td></td>
<td>- Sn·8Zn·3Bi (for handling in open atmosphere) (Equivalent melting point to conventional solder, low-temperature mounting possible)</td>
</tr>
<tr>
<td><strong>No. of specimens</strong></td>
<td>4 combinations, 5 pieces each (n=5)</td>
</tr>
</tbody>
</table>

Table 1. Test specimens

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### Table 2. Test conditions

In this evaluation test, the conductor resistance of the soldered joints is continuously measured during the Combined Environment Test. Failure is determined by changes in the measured resistance, but the main focus of the test is on the joint strength measurements taken after all the tests have been completed. Fig.6 shows the test environment, and Fig.7 shows joint strength measurements.

<table>
<thead>
<tr>
<th>Comparison test conditions</th>
<th>Time: 500 hours each</th>
<th>Joint strength measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) High Temperature Test:</td>
<td>125°C</td>
<td></td>
</tr>
<tr>
<td>(2) Vibration Test:</td>
<td>25°C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frequency: 59±5Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acceleration: 9.8m/s²</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sweep speed 1 min/single sweep</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Combined Environment Test (high temperature + vibration) conditions</th>
<th>Time: 100 hours</th>
<th>During test: Continuously measuring contact resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time: 100 hours</td>
<td>125°C</td>
<td></td>
</tr>
<tr>
<td>Temperature: 125°C</td>
<td>Vibration:</td>
<td>Frequency: 54±5Hz</td>
</tr>
<tr>
<td>Vibration: Frequency: 54±5Hz</td>
<td>Acceleration:</td>
<td>9.8m/s²</td>
</tr>
<tr>
<td>Acceleration: 9.8m/s²</td>
<td>Sweep speed:</td>
<td>1 min/single</td>
</tr>
<tr>
<td>Sweep speed: 1 min/single</td>
<td>(at 100% increase)</td>
<td></td>
</tr>
<tr>
<td>Failure determination: 2x initial resistance</td>
<td>After test:</td>
<td></td>
</tr>
</tbody>
</table>

*JIS conformance (Japanese standard)*

“Test methods for lead-free solders – Part 6 Methods for 45° pull test of solder joints on QFP lead”
Fig.7 Joint strength measurements

As Fig.7 indicates, results vary depending on the solder/plating combinations. In all of the combinations, the Combined Environment Test produced greater loss of strength than did the other tests. (The Combined Environment Test ran for 100 hours, while the other single stress tests ran for 500 hours each.) This indicates that the Combined Environment Test can be considered an effective acceleration method for joint strength. The acceleration is assumed to result from the mechanical stress of vibration being applied during lowered joint strength at high temperature.

Joint strength degradation at high temperature is said to be caused by the growth of the intermetallic compound layer, and it is thought that the different characteristics of the solder composition cause variations in joint strength.

1.2 Failures

1.2.1 Detrimental effects of cardboard insulating properties – Thermal Test using the temperature and humidity chamber

- Test contents
  Heat treatment of liquid chemicals. 20,000 30-ml bottles of liquid chemical treated for 2 hours with a liquid temperature of 60°C, or for 12 hours with a temperature of 50°C. Application of excessive thermal stress induces chemical change, while insufficient stress leaves the specimen untreated.
  The specimens were put into cardboard boxes with individual compartments and placed on shelves. Even a slight breeze would blow the lids open.
- Test equipment used
  Walk-in type temperature and humidity chamber (Espec domestic model TBL-6,
Accelerated testing

overseas model EBL-6. Inside dimensions: W4000 x H2600 x D3000 mm

- Defect phenomena

On some of the extra thermal monitors provided, the temperature did not reach 60°C, but was dropping despite the fact that the temperature inside the chamber attained a stable 60°C.

Mistaking the thermal insulating properties of the cardboard (insulating properties were higher than anticipated) caused the test to fail. The test operator took the insulating properties of the cardboard into account and proposed treating only the containers, but a compromise was made by merely opening the lids of the external cardboard packaging to run the test. The compromise was a result of such factors as short delivery times, product value (products returned if flaws found on container packaging), and liquid temperatures being monitored using dummy samples. However, even after the temperature inside the chamber reached 60°C, the liquid temperature in the (aforementioned liquid temperature)thermal monitors placed in the center of the cardboard boxes did not reach 60°C, but continued to drop.

The reasons the temperature dropped:

- The specimens were stored at 5°C until they were brought out for testing.
- The containers were individually compartmentalized inside the cardboard boxes, providing an effective barrier to the temperature inside the chamber.

The surrounding specimens inside the cardboard boxes had reached treatment temperature, producing large variations, and testing was temporarily suspended.

The operator had uncritically accepted the pre-test conditions requested by the client, and a lack of diligence in checking the pre-test conditions such as equipment and specimen quantity (from room temperature or from 5°C) led to failure.

After all, all items were removed from the cardboard boxes and placed on the shelves for treatment.

1.2.2 High temperature measurement method using thermocouples – Temperature measurement above 350°C require handling with thermocouple type K
(nickel/chromium/nickel-aluminum, hereinafter "Type K") (IEC60584 and JIS C1602)

- Test contents

Confirm temperature performance of items already delivered. Using several sheathed thermocouples (Type K), repeatedly measure each point inside the product chamber, and when the opportunity presents itself, measured values have drifted and the phenomenon is not reproducible.
• Defect phenomenon
Occurrence caused by Short Range Ordering. (Refer to Fig.8.)

SRO (Short Range Ordering)

Fig.8 SRO overview (Short Range Ordering)
The test operators, having some knowledge about sensors, were also aware of SRO (Short Range Ordering), which is included in JIS standards. However, when the defect occurred, they did not take the occasion to wonder, “Is this SRO?” Simply studying about a phenomenon is not enough. One must have some hands-on experience. For reference, Fig.9 presents experimental data about SRO received from sensor manufacturers.
The sheathed thermocouples (Type K) used in taking measurements were burned in with the sheath sections almost entirely at 500°C before being tested and measured under the conditions in Fig.9.
1.2.3 Notes about failure caused by dew condensation moisture – water droplets from an unexpected source

Dew condensation moisture can catch the operator off guard in the Temperature and Humidity Test. Dew condensation was produced on the ceiling by the test equipment, and this moisture dripped down onto the specimens. The dew condensation dripped onto the lead wires used for taking measurements and applying current, and from there found its way down to the specimens. Such occurrences are rare, but once in the Combined Test (temperature and humidity + vibration), during the cycles of the temperature and humidity conditions, dew condensation formed on an aluminum jig used for vibration. During vibration acceleration, this dew condensation began dancing around and splattered all over the specimens.

Of course one must carefully examine the temperature and humidity profile considering the dew condensation on the specimens. When dew condensation forms in various sectors (e.g., inside the test chamber and on the leads for taking measurements), one must take necessary precautions such as making guides to force drainage flow so that the moisture will not get on the specimens.

In one case failure occurred in joint reliability of the lead wires used in checking joint reliability. To evaluate the joint reliability of PCBs using lead-free solder, lead wires to measure conductor resistance were attached with solder. However, the solder joints of the lead wires were so poorly attached that they failed before the joints that were being evaluated, ruining the test. When a broken wire was detected, the specimen was checked and the tester found a broken lead wire that was being used to measure the specimen.
The current trend when checking joint reliability is toward increasing the number of specimens as well as the number of measurement points, causing overcrowding. When a mistake is made it can take a while to catch the problem, and during that time the possibility is high that excessive force may be applied to other specimens, causing identical defects.

The need for skillful soldering is important, but we would also suggest that it is a good idea to increase the size of the solder pad used to connect the measuring leads when possible. In addition, one must carefully consider other aspects such as taking care not to put excessive force on the measurement leads when placing the specimens into the chamber. If a defect should be caused, after removing the item, find a place for it that has a moderate amount of space for making repairs.

When using the aforementioned measuring equipment, a number of lead wires run in and out of the environmental test equipment chamber. While it is an extremely uncommon example, on one occasion when an independent measuring circuit was set up, a number of long lead wires were used. These leads became antennae, picking up noise from surrounding equipment and inducing changes in the measured values. As such an example was published in a professional magazine edition, that example is presented here in Fig.10.

Wiring pattern and I/O cables serve as antennae emitting noise. When a cable is connected, the electric field intensity of emitted noise may increase more than 100 times.

* Excerpt from “Electronic Technology”, Nikkan Kogyo Shimbun, Ltd.)
Pitfalls in accelerated testing

Below are some mistakes that can easily be made by the test operator lacking experience in testing.

2.1 Are you overestimating the reliability of your test equipment?

Despite being called environmental test equipment, some variation does occur when reproducing some of the environments.

These variations might include items depending on the position of the specimen inside the chamber (temperature and humidity uniformity), items depending on the time elapsed (temperature and humidity fluctuation), and items depending on the test equipment model and manufacturer.

2.2 Are you properly applying environmental (or other) stress?

This item is related to the previous one (2.1). It is possible to have wide variation among specimens in the chamber depending on the number of specimens that are put into the chamber together and items restricting air flow depending on where they are placed.

Just as in the failure examples, they may seem at first glance to be under stress when in fact the inner section may be under no stress at all. If there is any chance of this occurring, precautions must be taken, such as monitoring the environment in the vicinity of the specimens and monitoring electrical signals.

2.3 Are you applying stress unrelated to the test purpose?

As in the failure example presented in paragraph 1-2, when running the Temperature and Humidity Test, care must be taken with dew condensation moisture, which can produce a variety of unwanted effects in the specimens. The effects on the specimens from high humidity differ from effects due to water dripping on the specimens.

When applying electrical stress, the operator must confirm that the intended load is directed at the intended sector. Electrical stress may be applied unintentionally to specimens due to the operator overlooking something or assuming that everything is all right.

The Vibration Test can run into complications with the jigs and fastening methods, but the lead wires attached to the specimens for measuring can also suffer failure caused by vibration. The lead wires may be fastened while looped or stretched and it is necessary to confirm that they do not place added stress on the specimens.

Some tests may be based on the designers intuition and experience using a generate-and-test model, such as Prototype → Measurement data → Countermeasures (a repeated cycle), but it is also necessary to predict whether stress unrelated to the test purpose may be applied.
2.4 Are you watching for failures predicted by the test design?

Failure includes a variety of aspects. Failures unrelated to those intended by the stress applied may be mixed in with the results. The test results must be checked and thoroughly scrutinized. When checking joint reliability, failures may be produced by exceeding a specified level of resistance. However, you must confirm that these failures are due to joint abnormalities and not to a broken measurement lead wire. The “suspended function” in a certain subsystem may be a failure, but abnormalities in various sectors could cause a suspended function failure. The same may be said for an interrupted power supply. If that suspended function is not a target of the test design, you must throw out the results and analyze the data.

3 Conclusion

These key points are crucial to successfully performing the Accelerated Test.

- Accurately apply stress conforming to the purpose of the test.
- Thoroughly grasp the purpose of the test.

Have you confirmed what has broken and how (and what has not broken)?

Have you confirmed what problems have occurred and what problems have not occurred?

- Define clearly what the failure entails.
- Attain the ability to scientifically analyze how products fail.
- Have sufficient knowledge and experience to understand what types of failure occur.

Any of the above items seem patently obvious, but when actually running a real test it is easy to get caught off guard and experience test failure. Until you have gained experience, one means of avoiding failure is to have an experienced operator check your operation before you begin the test.

It is only a test, but it is a test. That is my frank opinion.

I shall be delighted if whatever experience I have managed to accrue serves to provide some sort of benefit to someone attempting to gain experience in accelerated testing.

Bibliography

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