

Fundamental Concepts of Environmental Testing Techniques in Electricity and Electronics

Part 4: To carry out effective environmental testing

Toshio Yamamoto*

For the final article in this series, we would like to present a number of items for reference to aid in carrying out effective environmental testing.

When environmental testing is done according to the manual provided, the work can at least be completed, but would it not be possible to go a step further and obtain one's own measures to carry out actual environmental testing more efficiently? Additionally, there are a number of smaller details that may not be major items within actual environmental testing, but are being overlooked. We would very much like to have testers check to see whether they are overlooking these points. We believe this will be time well spent. Effort invested in looking at environmental testing in this way and accumulating these small details will pay big dividends in future testing work.

Contents

1. Introduction
2. Environmental testing performed as reliability testing
3. Key points for environmental testing and environmental stress
4. Key points in performing environmental testing
5. Practical use of standard tests
6. Guidance for test planning
7. Summary

1. Introduction

The establishment of modern environmental testing relies in large part on the Agree Report¹⁾. If the statement is limited to the field of reliability, the characteristic merit of environmental testing, the report set environmental testing methods for quantitatively measuring the transition to failure of products in a variety of environments encountered in product storage, shipping, and use. The report also quantified evaluation of accelerated life testing. As a result, it became possible to establish methods for quantitatively evaluating failure, and to clarify the relationship between product failure and the results of environmental tests and accelerated tests. This has promoted improvements in the reliability of industrial products, particularly in modern electrical and electronic products.

2. Environmental testing performed as reliability testing

In environmental testing, one type of reliability testing, you are surely aware that there are many types of testing other than temperature and humidity testing, but whatever the type, testing can be broadly classified as testing done within the range of the upper and lower limits (particularly the upper limits) of the environment of actual use, or as testing done under severe conditions that exceed the normal range of use. The first type, called simulation testing, imitates actual environmental conditions and needs no further explanation here. The second type is performed under severe environmental conditions and can be broadly separated into "accelerated testing" and "survey testing for weaknesses". However, from the standpoint of reliability, both require reproducibility²⁾ of test results performed under identical conditions, and both require the scientific compatibility to obtain identical results for the same test using different test equipment.

*Technical Planning Department

Testing performed under severe environmental conditions can be seen as either accelerated testing performed within the range to obtain results of the same failure mode occurring in the field, or as testing to seek out the weaknesses of the individual product, called survey testing for weaknesses. The latter form can produce failure modes that differ from those found in actual use.

The difference between these two types of testing is that accelerated testing can be seen as obtaining results with general social applications, while survey testing for weaknesses can be seen as done for research purposes for special environments (e.g., artificial testing conditions, locations, and time) that are not particularly applicable for society in general. Failure to understand this distinction can lead to mistakes in test performance levels and in combining test conditions that can result in mere destructive testing, so strict care must be taken on this point.

3. Key points for environmental testing and environmental stress

When environmental testing is done as accelerated testing, it is fundamental that only targeted environmental conditions be applied to the test specimens, and that no other stress be applied. However, in reality, stress outside the targeted conditions occurs quite often, so this point requires attention. In addition, targeted stress may not be occurring appropriately due to problems with measurement technology or technical misunderstandings, so prior study and preparations are crucial to controlling the test environment.

3-1 Temperature and humidity environments and excess stress

In actual test equipment, air in the test space is usually circulated by force using a fan. In such cases, wind velocity is not uniform among equipment manufacturers, and in some cases is not even uniform in different pieces of equipment offered by the same manufacturer. Sometimes different test equipment is used with no change in the type of test. In such cases a test must be run during the preparation period using dummy specimens to check whether any differences in stress occur even under the same environmental conditions. One must not be confused by apparent temperature and humidity indications or conditions. Even in a simple temperature test, the test environment required by the test consists not of the apparent temperature, but of the stress environment applied to the specimen as thermal energy, in which ideally the test space can be assumed to be homogenous. Thermal conductivity of test specimens differs according to the surface conditions and shape of the specimen, but basically conductivity is determined by air characteristics and wind velocity, and so wind velocity has a major impact as a parameter that fluctuates. Normally, in proportion to wind velocity conductivity is raised to power in the range from 1 to 1.25.

On the other hand, most temperature and humidity testing equipment uses a system constructed so that water is heated in a humidifier provided in the chamber, the resultant steam is sent into a dehumidifier, which condenses excess steam and returns it to the humidifier, and then the required amount of steam is mixed into the circulating air

and forced into the test chamber with a powerful fan. The specimens are constantly exposed to fresh moist air for testing. One point requiring attention in humidity testing using this type of test equipment is that comparatively large droplets of water condensed by the dehumidifier or splashing up from the surface of the boiling water in the humidifier can ride the strong air currents into the test chamber. The stronger the air currents, the greater the quantity, and the danger of a large quantity of water droplets getting into the air currents is particularly great during the temperature and humidity ramp-up, in the stage going from the initial test chamber environment until the humidity setting is reached. As a result, these water droplets fall onto the surface of the specimens, giving them a higher moisture level than the vapor setting. For example, if water droplets fall between the exposed terminals when testing specimens such as surface-mounted multiple pin IC's, the dielectric strength is seriously weakened, cross-linking is formed, and breakdown occurs. This type of phenomenon affects test reproducibility and can lead to mistaken test results. Most current test equipment lacks the ability to cope with this defect. Because of this, the tester must use a practical test technique such as ramping up the temperature in advance and raising the surface temperature of the specimens above the dew point temperature before ramping up the humidity, or else arranging the specimens in the chamber in such a way that water droplets from the air currents are not so likely to fall on them.

3-2 Key points in HAST

Let's consider HAST (Highly Accelerated Stress Test) as a typical example of accelerated testing. The HAST test method was developed to speed up the evaluation of humidity endurance of specimens such as electronic parts sealed in plastic. This is a highly accelerated test using extremely severe stress conditions that far exceed the environmental endurance rating of the specimen. In such conditions, the occurrence of unwanted stress can easily lead to major errors in the test results. Because of this, even more care is required than in normal temperature and humidity testing. If we do not strictly control the occurrence of unwanted stress, our ability to obtain reproducible results becomes very uncertain.

Especially with this level of severity of test conditions, the test method may be unsuited to some specimens due to their materials, construction, or equipment type. Furthermore, the test method may produce failure modes that greatly differ from those found in the field, and we cannot say for certain to which specimens this method can be applied. Because of this, we must study carefully in advance whether this method is suited to our purposes. For these reasons, we must be aware of the fairly limited range of application of this type of test.

When selecting test equipment for environmental testing above 100°C, we must select equipment with superb performance in temperature and humidity control or face uncertain reproducibility. Environmental control becomes particularly critical with humidity levels near 100%, where a difference of $\pm 0.1^\circ\text{C}$ means the difference between a saturated and an unsaturated environment, or in some cases a super-saturated environment, soaking the surface of the specimen in water.

By the way, the nature of most products results in a conflict between resistance to high heat and resistance to humidity: raising one tends to lower the other. It is crucial to confirm whether this property exists in individual specimens, and it is essential to fully study the product construction and material in regard to performing a test.

3-3 Temperature cycle testing and thermal shock testing

Generally, no clear distinction is made between temperature cycle testing and thermal shock testing, although quite often tests using air as a heat transfer medium are called temperature cycle tests, while those using a liquid medium are referred to as thermal shock tests.

Whether the heat transfer medium is air or a liquid makes a big difference in the time period of thermal stress, and from the standpoint of thermal conductivity, thermal shock testing is the more severe. The problem, as expressed in section 2, is the lack of clarity about whether this test is an accelerated test or a survey test for weaknesses. Regardless of how it is seen, thermal shock testing has a strong tendency to be used as a survey test for weaknesses.

Next, let's look at temperature cycle testing from the standpoint of how it handles reliability.

In its usage environment, a product is exposed to daily temperature fluctuation as well as temperature fluctuation from being turned on and off, resulting in mechanical fatigue induced by temperature fluctuation. Except for heat-generating parts, generally this temperature fluctuation is sluggish, there is only a slight temperature differential between the inner section and the surface of the electronic part, and mechanical stress results from the conflict between structural materials and shape. Temperature cycle testing corresponds to these conditions and can be understood as repeating the accelerated conditions in a short time period and increasing the temperature differential to increase the severity of stress. Therefore, this can be understood as pure and simple accelerated testing. To further reduce testing time, the temperature gradient must be increased, but creating too great a temperature differential between the inner section and the surface of the electronic part introduces the possibility that this will no longer be essentially a temperature test. The limits of the temperature gradient depend on the product type and size, and so we must be careful not to assume that creating an excessive temperature differential will result in accelerated testing.

On the other hand, in thermal shock testing, a sudden temperature change is applied to the surface of the test specimen, creating a temperature change gradient between the inner section and the surface of the electronic part in a very short time, and can be understood as an attempt to evaluate thermal shock. However, this can be applied to testing parts for special applications (e.g., electronic parts built into airplanes that repeatedly undergo rapid raising and lowering) and to testing to flush out weaknesses for parts with limited purposes in a limited range during the manufacturing process. We must be aware that basic to this testing is the fact that the level of test conditions will depend on the size, shape, and especially the thermal capacity of the test specimen.

In either type of test, the factors causing temperature changes in the test specimen itself consist of the air or liquid temperature around the specimen, the wind velocity or current flow rate, the thermal capacity and conductivity of the specimen, and the shape and surface condition of the specimen.

4. Key points in performing environmental testing

When performing environmental testing, it is natural that the manner of progressing the test will depend on the purpose of the test. For example, the method of product failure analysis can be selected from among various methods depending on whether it is for academic purposes, i.e., a method of analyzing product failure, or for simple routine business such as lot inspection of manufacturing products or acceptance testing of purchased parts and externally ordered parts.

Particularly in the case of academic purposes, to perform testing effectively, a little attention affects validity. For example, there are matters such as testing products of different companies simultaneously, or making observations taking care for changes and abnormalities that are not related to current test results. As a result, when examining the test specimens closely after the test has been completed, quite often not only failure precursors, but also abnormal failures are found, making it clear that the test facilities or the test method were not appropriate. Also, after the test has been completed, it may seem that no abnormalities have occurred, but upon disassembling and analyzing the specimens they may be right on the verge of failure.

Considerations when performing these types of tests include:

- (1) How much interest does the tester have personally in the test?
- (2) Does the person in charge of development have a serious concern in the reliability of the specimens to be tested?
- (3) Is the tester experienced in reliability testing?

Matters such as these directly and indirectly affect the persons involved. When factors related to the persons involved accumulate, we can express the result as know-how, and they make up an aggregate of know-how for specific tests. (In one sense, there is no method involved, but this know-how should be appropriately passed on to one's successor.)

On the other hand, when performing testing as a matter of routine business, most tests are handled as general standard tests regardless of whether public or private. This has brought about a situation in which it is impossible to understand the actual purpose of the testing being personally attempted, and standard test methods are applied automatically. Actually, even in an IEC standard test method used in public standards, there always exists a background to that test method, and it does not exist as vague standards. In other words, background information and general information and guidance explain the background. The structure of the IEC60068 series has the following basic form.

Part 1: General information and guidance

Part 2: Tests

Part 3: Background information

Part 4: Information for specification writers

Part 5: Guide to drafting test methods

Currently, these are not provided fully in each individual test method, but they cannot be overemphasized.

To return to the original subject, if we make a conjecture as to how this state of affairs has come about, we can assume that it has come about against the background of test work becoming more strongly characterized as standard work with the spread of quality control activity, with even those lacking knowledge in the field of reliability being able to perform tests (as work).

Opinions on how a variety of test methods should be applied will depend on the standpoint of the manufacturers and users (e.g., acceptance tests vs. delivery tests). Also, in many cases test methods that are called by the same name differ greatly from the standpoint of the particular field of technology (e.g., electric, electronic, machinery, or the chemical industry) for comparable products. Therefore, when differences exist in particular fields of technology, mutual understanding of terms must be agreed upon for use in the pre-contract stage of negotiations. Because of this, we must be aware that sometimes we must spend sufficient time to resolve problems in advance before the testing contract is put into effect.

5. Practical use of standard tests

At this point, we will take up the use of IEC standards as public test standards.

We have already pointed out the impossibility of prescribing standard environmental tests that can be applied comprehensively to all individual products. However, it is possible to suggest tests that are appropriate to a large number of products. (Surely, the IEC test standards can be seen as being for this purpose.) Also, when modifications are made to adapt conditions to specific environments, the modified conditions must be clearly presented when planning the test.

When selecting a test method, we must be aware that the values for test conditions (test severity) within the standards are merely representative values rather than environmental conditions actually encountered by the individual products. If certain products are known in advance to encounter environments exceeding the conditions given in the standards or to have special endurance, testing with fixed conditions can of course be eliminated. For example, if the conditions in a storage test have been covered in the shipping test, it would make little sense to go ahead and carry out the storage test.

Next, let's take a look at the purposes for different tests.

(a) Storage testing

Storage testing is based on the environmental conditions to which the product is exposed during the continuous time period when it is stored. However, in the standards, storage refers to the time from product manufacture until initial use, excluding the time during shipping.

The product should be tested under conditions occurring during storage, but for example if the product is in packaging during storage, as a rule it should be in packaging during testing. Also, if the product is stored in both packaged and non-packaged states, it must be tested in both states. We must remember that for certain types of test conditions and products, testing conditions are more severe with the product in the packaged state than when the package has been opened. For example, when products are hermetically sealed in packaging and vapor is trapped inside the packaging, we must remember that temperature changes can cause dew condensation. Also, a puncture in the seal can lead to a phenomenon called breathing, in which humidity from the surrounding air is pulled into the package.

(b) Shipping testing

Testing for shipping is based on the environmental conditions to which the product is exposed during the time period when it is being shipped. Shipping can be done over land, on the sea, or in the air. We shall use the term shipping to refer to the time in which the product is transferred from one site to another after being shipped from the manufacturing plant.

Products are tested under shipping conditions applicable to the individual product, and if a product is shipped in the packaged state, it should be tested in the packaging, and if some items are shipped without packaging, testing must be done in both states, the same as in (a) above.

(c) Usage condition testing

Usage conditions include every condition to which a product is exposed during its life cycle, including product usage, down time, maintenance, and repairs. However, the environments inside the individual product equipment should be excluded in this case, and determined separately.

Relevant specifications set details such as whether a product should be operated during environmental testing, and the need for measuring before, during, and after testing. The sequence of these tests is also prescribed in relevant specifications. Combining various pre- and post-tests with the targeted testing obviously has some merit, but creating too unique a sequence can require excessive concern with suitability, and care must be taken with excessively increasing the expense of testing.

(d) Test (exposure) time

Test time (recommended duration) is prescribed in the standards, and this value can be understood as a value backed by full experience in confirming results on products at the time the standards were established. Therefore, when a lot of time has elapsed since the standards were established, they may not be appropriate to the current level of technology, or they may serve a different purpose, so the values in the relevant specifications are given priority.

(e) Combined testing

Combined testing can obtain results that more accurately reflect actual environments than can individual tests done serially. However, we would like you to realize that combined testing doesn't achieve validity until you clearly understand the combined conditions that should be anticipated within the dynamic environment.

6. Guidance for test planning

At this point we would like to think beyond the limitations of tests for individual environmental factors such as temperature and humidity, and consider instead environmental testing within the relationship between the product and its broad natural environment.

(a) Climate testing

Reproducing all the various phenomena of the real natural world in a limited space such as a test chamber or test equipment is absolutely impossible. The most realistic approach is to construct environmental factors such as temperature and humidity and create individual test environments. The IEC60721 series will serve well to explain complex combinations of conditions found within a typical environment.

Various elements within a wide variety of environments are themselves difficult to reproduce, or the reproduction may not be realistic due to the complexity. Therefore, the realistic approach is to carefully study the affects of each factor in advance, and each affect must be clarified in advance to the fullest possible extent.

(b) Exposure to the sun

Specific environmental testing for general exposure to the sun's rays is not covered in the IEC60068 series. In most cases, an imitation sun spectrum is used in testing for exposure to sunlight. However, actual problems include various restrictions within the test chamber as well as extreme difficulty in imitating sunlight exposure within the test equipment. The technique developed for that purpose is to create a spectrum test divided into the three spectral bands of infrared, visual, and ultraviolet light. Then, sensitive products are assessed in these individual conditions and tests are performed in accordance with specific purposes.

We will present for reference three major phenomena caused by exposure to sunlight.

1) Ultraviolet rays and photodegradation

Most of these affects occur in the ultraviolet spectrum. However, similar affects are known to occur in the visual spectrum as well, so we must be careful. Examples of these influences can be found in fading and in fogging of semi-transparent plastic. Most tests to evaluate these affects can be done at the level of materials and parts, and are also possible for completed products. With completed products, increased heat absorption and heat rises within the product itself add to the results such as causing color paint to fade.

2) Thermal effects

The following methods are used to evaluate individual products in regard to the determination of durability and failure mechanisms in relation to rising temperature.

i) Temperature rise

The sunlight load causes a marked rise in the surface temperature of the product and its immediate vicinity compared to the ambient temperature. There are two ways to imitate this temperature rise. One is to use the 15°C rule (the amount of temperature rise determined from experience). The other is to use a heat lamp to raise the surrounding temperature.

ii) Thermal gradient

Sunlight irradiation comes from a single light source, so the thermal effect in the open environment is directional rather than equal. Therefore, different thermal affects are received on different parts of the exposed product. This sectional heating up exceeds the tolerance for temperature differential of the product and causes sections of the material to expand. This causes problems such as defects in the seal and changes in the performance of electronic parts. To handle these problems, a directional irradiation heat source is promoted. Then, when imitating this condition, a section inside the product with an unrealistic temperature rise must be avoided by maintaining appropriate air circulation.

c) Mechanical environments

In most cases mechanical environments are induced or artificial environments rather than natural environments. Testers must exercise due care in analyzing each element in the life cycle profile in the mechanical environment applying such stress as vibration, shock, and noise to the product.

1) Vibration testing

Sine wave vibration testing is limited by measurement methods and testing limitations, but historically it has been applied to most products. On the other hand, in most cases random vibration is becoming used for diverse applications as a test that can recreate conditions realistically. Sine wave vibration produces limited conditions (e.g., products containing rotating parts, such as rotors or airplane propellers), but, contrary to past circumstances, sine wave resonance investigation should already be considered as being at a level unsuited to current investigation.

2) Shock testing

Shock testing is applied to products exposed to comparatively rare, non-repetitive circumstances encountered during operation, shipping, or use of the product. This measure is applied to cover product brittleness encountered by every package in these environments.

Typical affects of shock include the following.

- a) Permanent damage due to overload
- b) Sudden damage to or fatigue of materials
- c) Failure due to changes in friction or impedance between parts.

7. Summary

Environmental testing varies according to the different purposes to which it is applied. Even when tests are called by the same name, in many cases they will differ to some extent because of the test details. This situation even applies to tests that conform to public test standards, and in this type of situation the success of the test can depend upon the information exchanged by the tester and the party requesting the test, as well as their mutual understanding. Acquiring a wealth of experience in performing tests is extremely important, but in many cases this can result in the tester jumping to a hasty conclusion about the gist of what the party requesting the test wants, and as a result missing the most important aspect of the test. As an act of performing work, the test can be run merely by following the manual, but in reality the tester must acquire the habit of looking at the details of the test theoretically from a scientific standpoint. Even in that sense, the test varies from the script each time, and we would like to encourage leaving a written record of each test. Accumulated know-how also can be theoretically supported, clarifying the scientific basis by the process of rereading these records. This can help one to clearly grasp key points that must be caught. This is the main point of “effectively performing environmental testing”.

-
- 1) **AGREE Report:** Advisory Group on Reliability of Electronic Equipment, report established August 21, 1952 (US Dept. of Defense)
 - 2) **Reproducibility:** Proximity of individual results obtained with identical test specimens and testing methods under differing conditions (different testers, different tools and equipment, different test sites, or different time period)
 - 3) **Repeatability:** Proximity of test results continuously obtained with identical test methods, identical test specimens, and identical conditions (same testers, same tools and equipment, same test site, and same time period)
(Above definitions from ISO3534/3 Statistics: Terms and Symbols, in Part 3, Test Planning)