

ESPEC

# TECHNOLOGY REPORT

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Evaluating Reliability and  
Environmental Testing

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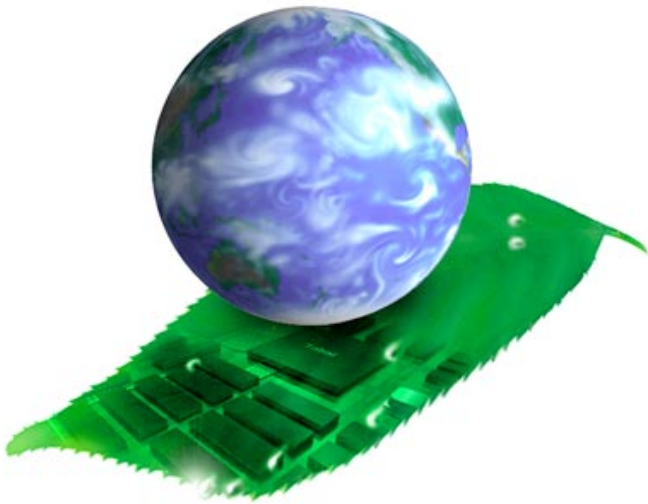
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## Our Philosophy

We at TABAI ESPEC are continually pursuing perfection. In our ongoing struggle to realize this ideal, we have established our Corporate Mind, which we proudly use as the basis for all our efforts. This Corporate Mind defines for us our present and future goals, directions and actions. At TABAI ESPEC, where “Environment” is our business, we offer aid for new technological developments and a more certain and improved living environment. With “Progress to Perfection” as our corporate policy, we aim to become the company, firstly “with public recognition by having our original line of business, and our own original product sphere by virtue of our original technology”, and secondly “with intellectual raison d’être of such that as specialists can, assist our clients and industry in setting up various issues and in finding answers to them”. This total concept we call ESPEC. From our internationally minded product development, to our thorough after-service, all our activities originate in this concept of ESPEC. ESPEC is the foundation upon which we manufacture products with superb performance, functional design and excellent cost-performance — our ESPEC.

**ESPEC — our philosophy, our goal.**

## Corporate Data **TABAI ESPEC CORP.**

<b>Company Name:</b>	TABAI ESPEC CORP.
<b>Date founded:</b>	July 25, 1947
<b>Date incorporated:</b>	January 13, 1954
<b>Paid-up Capital:</b>	6,778 million Yen (As of September, 2000)
<b>Chairman:</b>	Eiichi Koyama
<b>President:</b>	Kiyoshi Shimazaki
<b>Senior Managing Director:</b>	Yoshinobu Yamada
<b>Managing Directors:</b>	Susumu Nojii Toshikazu Adachi Nobuyoshi Shin Shigemi Suzuki
<b>Directors:</b>	Eishiro Hizukuri Yoshio Nakai Hiromichi Fukumoto
<b>Regular Auditor:</b>	Katsuyuki Kakihara
<b>Auditors:</b>	Shoichiro Yoshioka Takuichi Omura
<b>Employees:</b>	605 (plus 71 temporary employees)

## Product Guide

### Environmental Test Chambers

Temperature (& Humidity) Chamber  
Temperature (Humidity) & Vibration  
Combined Environmental Test Chamber  
Walk-in Type Temperature (& Humidity) Chamber  
HAST System (Highly Accelerated Stress Test System)  
Thermal Shock Chamber  
Temperature Chamber (Industrial Ovens)

### Measurement Evaluation Systems

Ion Migration Evaluation System  
PWB Conductor Resistance Evaluation System  
Environmental Test Chamber Network, E-Bus

### Burn-in Test Systems

Wafer Burn-in System  
Dynamic/Monitored Burn-in System

### Automated Production Equipment

Automatic Clean Cure System  
High Speed Clean Oven for Glass Sheet

### Laboratory Chambers

### Biomedical Chambers

### Agribusiness

Plant Factory  
Phyto-tron (Environmental Control Chamber for Plant)  
Growth Chamber

### NOTE:

Some models are available only in the limited countries.

*Even the field of reliability has its own examples of short-term cyclical fashions. The latest trendy topic is “lead-free soldering technology”. Naturally, the field of environmental testing has not escaped this vogue, and has been drawn into the discussion. The consensus has come to regard the topic as a familiar topic taken up for human coexistence with technology. However, we should not be convinced too easily. Past experience is replete with examples of hoped-for improvements turning out to make matters worse. Merely because something has been initiated by quality control technology, or by reliability technology, does not automatically produce reliability. I believe that the constant topics of reliability should be pursued to the utmost by bold and careful actions to eradicate the lack of understanding.*

### 4. Environmental test application

#### 4-1 General points

Environmental tests can be divided into the following categories based on how the tests are applied. Please take note of these concepts, as they form the points of divergence for how the tests are utilized.

- |   |
|---|
| <ol style="list-style-type: none"><li>1) Tests run within the upper and lower limits of the product’s rated range of use</li><li>2) Tests run under harsh conditions exceeding the product’s rated range of use</li></ol> |
|---|

Tests run within the pre-established rated range of the product are in category 1). These tests can generally be assumed to be applied using existing standard test methods with no changes, and so we will not go into this category here.

For the tests in category 2), we must also consider the purpose of the test. Tests can be separated into two groups, both of which result in harsh environments. The two test groups are:

- (a) Tests run from a reliability standpoint using harsh environments to create accelerated tests capable of reproducing the failure modes occurring in the field, and
- (b) Tests run from a true technological standpoint producing failure modes not found in the field.

These tests are run to ferret out inherent weaknesses in the product. Accelerated tests in group (a) focus on failure modes found in the field, and so use for methods or results that can convince society in general. Accelerated tests in group (b) are used to seek out weaknesses, and there is an increasingly strong tendency to run these tests at specific stress level ranges for specific purposes. However, those tests results cannot be universally applied to society in general. Most of the various in-house tests run during product research and development fall within

this category.

By the way, when test results are provided elsewhere as information, tests conditions should be stated clearly, and while publicly providing results should be done prudently, it should be accompanied by the disclosure of as much incidental information as permissible. When a limited amount of information is provided, persons receiving the information can form misunderstandings based on their own presumptions about the incomplete areas. Furthermore, ignoring or deviating from the range of established levels and pre-planned logic in these tests should not be done lightly, as such a test approach generally results in little more than merely destroying the specimens.

Based on the above premises, I would like to summarize the key points for test application.

- (1) In the case of category 1) above, does the approach simply confirm specimen failure or verify that the specimen can withstand test conditions set according to test standards (either in-house standards or public standards)? In the case of category 2) above, is it not necessary to clarify in advance whether the approach will attempt to investigate the inherent weaknesses of the product? The answers to these questions will affect software selection in regard to such factors as the test procedures and the combination of test environment conditions, and will also affect hardware selection in regard to the functions and performance of the required test equipment and measuring devices. These decisions will also greatly affect test costs and time requirements.
- (2) The test environment conditions could be constructed through diligent reference to sources such as information from other companies and articles presented at the latest symposiums, but surely the best approach is to construct test environment conditions based on referring to prior in-house test results and creating in-house test plans and test specifications based on the experiences and results culled from

\*Strategic Planning Department

environmental conditions of past tests. The number of persons who have built up such a wealth of experience is quite limited. As a result, testers often must rely on various publicized data. Relying on such data requires the ability to discern whether information from another person's example is reliable data.

- (3) Just as in other types of reliability testing, one major problem with environmental testing is the amount of time required to run the tests. Although accelerated testing is an attractive solution to this dilemma, accelerated testing introduces its own problem of whether a single test with a single test condition can determine all failure modes. Also, merely using expensive testing with a high level of complexity is no guarantee of being able to obtain sufficient required data, and the use of a simple, inexpensive test does not preclude obtaining satisfactory results. In such situations, the deciding factors will be knowledge backed by interdisciplinary judgement and the amount of past data that has been accumulated (e.g., through the creation of a data bank).
- (4) The environment consists of such factors as temperature, humidity, vibration, and wind velocity, while the specimens being tested always have such individual factors as size, shape, surface conditions, characteristics of structural materials, and thermal characteristics such as heat capacity. In testing, one should not get carried away with immediate performance changes. It is more important to constantly monitor the conformance between the environmental conditions and the individual characteristics of the specimen.  
The principle that all test specimens be exposed to a uniform environment is fundamental to environmental testing. (In some cases, though, test aims require non-uniform conditions.) The principle of a uniform environment is reflected in IEC environmental standards which have adopted the requirement of a 1:5 ratio of specimens to test space as a basis for creating all types of test methods to secure a homogenized environment in the test chamber.
- (5) Once we have entered a special area such as the test room, we can easily be overwhelmed by the test results to the point of forgetting about the phenomena produced by the tests. Focussing too narrowly on the specimens can cause us to overlook the effects of proper layout of the jigs and fittings that form the interface between the test equipment and the specimens. Some test conditions can cause dew condensation to be generated by the jigs and furnishings. Such moisture can form water droplets that follow the lead wires and reach the electrodes of the specimens. Dew condensation can also drip from the ceiling of defective test equipment onto the specimens. Test preparations must always be done with an eye on the long-term reproducibility of test results.

## 4-2 Special considerations for environmental testing and environmental stress

When attempting to perform environmental testing, it is paramount that only the targeted environmental conditions affect the specimens. They must not be subjected to any other type of stress. These prerequisites must be strictly controlled, especially when running accelerated tests. Prior investigation and preparation are critical since stress level targets may not be suitable due to problems in measurement technology or due to technological misunderstandings.

### 4-2-1 Excess stress in temperature and humidity environments

#### (1) Wind velocity in test space

Most actual environmental test equipment uses fans to provide forced air circulation through the test space. In this type of circulation, wind velocity is not uniform among the equipment manufacturers, and in some cases is not even uniform for all types of equipment from a single manufacturer. This lack of uniformity presents a problem when acquiring new test equipment or using different equipment to run subsequent tests with conditions identical to those used before changing the equipment. Preliminary tests must be run using dummy specimens during the new equipment preparation period to determine whether differences in stress occur at the same settings. One must not be confused by the looks of the temperature and humidity indicators and conditions. Even test environments required for simple temperature and humidity tests do not simply consist of temperature and humidity indicators. The environments also include absolute quantities of energy and moisture as conditions, and those conditions can be seen as stress-producing environments for the specimens. The heat transfer coefficient of the specimens depends on the surface shape and conditions of the specimen, but basically the coefficient is determined by air characteristics and wind velocity. Thus, wind velocity within the test equipment has an extremely important effect as a parameter.

#### (2) Airborne water droplets during humidifying

General purpose temperature and humidity test equipment has a humidifying pan installed in the chamber. Water vapor is led from this pan to the air conditioning chamber. Excess water vapor is then condensed in the dehumidifier and returned to the humidifying pan, and the required amount of water vapor is mixed into the circulating air. Specimens are generally tested while exposed to this fresh, moist air, but one must be careful when using this type of test equipment for humidity testing. The moist air blowing into the test chamber can carry relatively large water droplets, and strong air currents can catch droplets splashing from the boiling water surface of the humidifying pan. Those large droplets can be blown into the test chamber. The stronger the air currents, the more likely this is to occur. Especially during the ramping up of the temperature and humidity from the ambient chamber environment to setting values, there is a danger that quite a large amount of these droplets can be mixed in with the circulating air. These droplets then fall onto the surface of the test specimens

and the amount of moisture placed on the specimens in the form of water droplets exceeds the original requirements. This in turn provides excess moisture, and for example, with parts such as surface-mounted multi-pin ICs, the moisture condenses and the droplets fall between the terminals, causing drastic weakening of the insulation resistance. Bridging results and the insulation is destroyed. This type of phenomenon affects test reproducibility, and can lead to incorrect test results.

### (3) Test specimens and dew condensation

To avoid dew condensation on specimens during testing, most current test equipment uses temperature and humidity level control programs that employ such controls as delaying the humidity rise until after the temperature rise, but older model equipment and equipment that doesn't have temperature and humidity programming features are not well-equipped to deal with this problem. Therefore, testers must employ practical techniques to reduce the opportunity for moisture adherence, including taking such measures as pre-heating the test chamber specimens, keeping the specimen surfaces above dew-point temperature, and aligning the specimens with the air currents (especially surface-mounted parts with terminals exposed).

#### 4-2-2 Special considerations for HAST

A more recent method of temperature and humidity testing called HAST (Highly Accelerated Stress Test) is able to attain greater acceleration than conventional tests. The HAST test method was developed to speed the evaluation of humidity resistance of plastic sealed electronic parts. These highly accelerated stress tests are performed under extremely harsh conditions that greatly exceed the specimen's environmental resistance rating. Therefore, any stress applied outside the targeted stress can greatly skew test results, creating the need for the utmost care to be taken at all times in these temperature and humidity tests. In other words, if the occurrence of stress outside the targeted stress is not strictly controlled, the test is in danger of not having stable reproducibility.

A test environment that is this harsh creates an especially inappropriate method for the materials, construction and type of some specimens. In addition, the failure modes that appear may differ greatly from those found in the field, and the test method cannot be applied to just any type of specimen. The tester must perform careful advance studies to determine whether this method suits the test objectives. For reference, I will include the test conditions in "IEC60068-2-66 Part 2: Test methods—Test Cx: Damp heat, steady state (unsaturated pressurized vapor)". (IEC standards do not list this test method as HAST.)

Temperature*1 (°C)	Humidity*2 (%)	Exposure time*3 (h)		
		I	II	III
110	85	96	192	408
120	85	48	96	192
130	85	24	48	96

Notes:  
 \*1.  $\pm 2^{\circ}\text{C}$  in the test space  
 \*2.  $\pm 5\%$   
 \*3. 0, +2 h

When selecting test equipment, we would do well to choose equipment with superior temperature and humidity control performance that achieve test stability. Although not listed in the standard severity, let's look at a case requiring environment control at humidity levels approaching 100 percent. In these conditions a mere  $\pm 0.1^{\circ}\text{C}$  is the difference between a saturated environment and an unsaturated environment, or at times successive super-saturated environments, and so water adsorption will result at the test specimen surface.

**Notes:** This is a rather broad statement, but the characteristics of many products are such that pursuit of high temperature resistance often produces a corresponding drop in humidity resistance. For individual test specimens, care must be taken to confirm such special characteristics. When performing these tests, we must make every effort to carry out careful studies in advance on the properties of specimen structure and materials.

#### 4-2-3 Temperature cycle tests and thermal shock tests

When reading collections of articles presented at reliability symposiums, we often notice that a clear distinction is not made between temperature cycle tests and thermal shock tests. This is often due to the definitions of both tests not being clearly distinguished, but normally tests using a gas (e.g., air) as a thermal medium are called temperature cycle tests, while tests using a liquid thermal medium are called thermal shock tests.

The difference between using a gas or a liquid as a thermal medium represents a striking difference timewise in the thermal stress placed on the specimen. The thermal shock test is far more severe from the standpoint of the thermal conductivity coefficient as well. The problem is, as noted in section 4-1, that it is not clear whether this is an accelerated life test or a test to search for weaknesses. In any case, there is a strong tendency to use the thermal shock test as a test to find weaknesses.

Let's first look at the temperature cycle test as a reliability test.

In its everyday usage environment, a product is exposed to the daily atmospheric temperature variations as well as temperature changes from being turned on and off. These temperature fluctuations produce fatigue (mostly mechanical) in the product, and this fatigue may accumulate. In parts that are not heat-generating, temperature fluctuations usually occur gradually, and in energy-saving electronic parts in particular, there is comparatively little difference between the internal temperature and the surface temperature. The source of mechanical defects can be traced to differences in structural materials, and differences in assembly and shape. Temperature cycle tests focus on these phenomena, and the conditions for acceleration can be understood as performing multiple repetitions in a short period of time, and increasing the temperature differential in order to increase the level of stress. Therefore, we can take this to be a thorough acceleration test, but increasing the temperature gradient too much in an excessive attempt to

reduce test time will produce too great a temperature differential between the surface and the internal parts of the specimen, introducing the danger that the temperature test will not reflect the original field environment. The limits of the temperature gradient will depend on such factors as the purpose and type of use of the product as well as its size. However, one should be aware that merely increasing the temperature gradient does not necessarily result in an accelerated test.

On the other hand, the thermal shock test subjects the specimen to abrupt surface temperature changes, producing a temperature fluctuation gradient between the surface and the internal parts of the specimen in a very short time. This test can be taken as an attempt to evaluate resistance to thermal shock, but it is often seen as a test for products with unusual applications (e.g., electronic parts used in airplanes that repeatedly undergo rapid changes in altitude), or as a test with specific aims for finding weaknesses in products during the manufacturing process. We must be aware that this test will require individual conditions depending upon specimen characteristics such as the size and shape of the specimen, and especially its thermal capacity.

In either of these tests, the factors producing the temperature fluctuations in the test specimen itself can be listed as the air or liquid temperature around the specimens, the wind or current velocity, the thermal capacity and thermal conductivity coefficient of the specimen, and the shape and surface conditions of the specimen.

### **4-3 Key points for running environmental tests**

Naturally, different environmental test aims call for different procedures. For example, measures used for failure analysis of test specimens will depend on such factors as whether the test aims are somewhat academic, or whether the test is simply run for routine business purposes such as inspecting production lots or checking customized products and purchased parts.

In the above-mentioned academic cases in particular, running effective tests requires taking a somewhat cautious attitude. For example, one should not simultaneously test products from different companies, nor should one introduce changes and abnormalities unrelated to test results. Otherwise, the tester may often find he is left with conjectures about other companies' problems, or that post-test investigation reveals failure precursor phenomena, or that the test equipment and test methods were not suited to the abnormal failure modes. Post-test analysis may even reveal that even though there were no electrical abnormalities, the specimen was on the verge of physical failure.

Persons directly and indirectly involved in running this type of testing will affect the tests differently depending on

- 1) how much interest the tester himself has in the test,
  - 2) whether the person in charge of development is seriously concerned about the reliability of the product to be tested, and
  - 3) whether the tester has experience with reliability tests.
- All of such conditions affecting the human factor taken

together add up to specific test know-how. In other words, we can see that environmental testing, just like other reliability testing, has many of its own unique technical aspects. (While this situation is unavoidable, the essential point is whether this know-how is passed on to successors.)

On the other hand, routine business tests in general, whether public or private, are usually handled as standard tests with responsibilities divided among different workers. This allocation of responsibility has led to a situation in which testers decide to run tests without understanding the original purpose of the tests, merely applying standard tests automatically. If we hazard a guess as to why this situation has occurred, it seems that along with the popularization of quality control activity, standard test characteristics have also become entrenched so that people are now able to carry out tests (as part of their jobs) without understanding the field of reliability.

Viewpoints on how the various tests methods should be applied differ between manufacturers and users (e.g., delivery testing vs. acceptance testing).

Even when identical test names and terms are used for a product subjected to testing, the meanings associated with such terms often differ widely in specific fields of technology (e.g., electrical, electronic, mechanical, and chemical). Therefore, especially when there is some disparity between the individual fields of technology, meanings of terms must be mutually agreed upon during the pre-contract negotiations, and these definitions should be written into the contract. By taking full advantage of this cost-effective time to solve problems before the test contract takes effect, these extremely important conditions should be revised and understood so that they do not interfere with the work at some later stage.

### **4-4 Using standard tests**

We have already seen that it is impossible to prescribe a single environmental test that can be comprehensively applied to every different type of product. However, it is possible to suggest multi-purpose test methods that can logically be applied to all products. Obviously, the IEC test standards exist for this purpose. As I have said before, when suitable conditions cannot be found in the prescribed test conditions (test severity), individual test specifications may be created and required test conditions may be employed and given priority. When the test conditions need to be modified, the modified conditions should be clearly written down and attached to the existing standards when writing the test plan.

When the endurance of a product is already known through prior use of environments exceeding the conditions prescribed in the standards, subsequent tests based on those established conditions can of course be omitted. For example, if the conditions for storage tests have already been covered by transportation tests, we need not go to the trouble of running tests using those storage conditions. Now, let's summarize the key points for the individual items of test use.

### **(1) Storage tests**

Storage tests are based on the environmental conditions to which a product is exposed during storage. However, when the term “storage” is used in the standards, it refers to the period from product manufacture up to initial use, excluding the transportation period.

The product is tested for normal conditions, but for example, when a product is packaged during storage, the basic approach is to have it packaged in the tests. If some products are packaged and some are not during storage, tests must be run for both conditions.

For some types of products and test conditions, we must be careful to note that packaging results in harsher test conditions. For example, moisture remaining inside the package in products in airtight packaging may experience dew condensation from changes in ambient temperature. Also, package leaking can generate the breathing effect due to changes in the external atmospheric temperature, sucking in more and more moisture from the ambient atmosphere.

### **(2) Transportation tests**

Transportation tests are based on the environmental conditions to which a product is exposed during storage. This can be on land, on sea, or in the air (e.g., in an airplane), but in this article we are using the word “transportation” to indicate the transportation period involved when a product is transported from one place to another after being shipped from the production site.

Products can be tested under a wide range of individual transportation conditions, but if they are packaged during shipping, they should be packaged during testing, and if they are not always packaged during shipping, both packaged and unpackaged conditions should be used during testing, just as in part (1) on storage tests above.

### **(3) Usage condition tests**

Usage condition tests are based on all conditions found during the life cycle of the product, including product use time, down time, time hooked up to peripheral equipment, and maintenance and repair time. At this point we shall ignore the environments of individual products inside equipment, leaving that matter for a later discussion.

Individual specifications are established for product operation during the environmental tests and for the measurements required before, during, and after testing. The sequence of these tests is prescribed in individual specifications. A variety of test combinations can be conceived of before and after the targeted test, but creating too specialized a sequence requires extreme caution, and may be linked to excessive test costs.

### **(4) Test (exposure) time**

Test time is prescribed in the standards, but considering when the standards were established, we can take “time” to mean “time enough to confirm the affects on the product”. A lot of time has elapsed since the standards were enacted, and if the standards no longer fit the current level of technology, or if we are running the test with different aims, these new settings should be written down in individual specifications and given priority.

### **(5) Compound tests**

Compound tests (test loads with multiple environmental factors) are supposed to produce results that are closer to those found in the actual environment than the results of simple tests run in sequence.

We should only acknowledge that the tests are effective after we have clearly determined the effects of the individual factors that make up the multiple conditions within the environments to which the specimen is exposed in compound tests.

## ***5. Pitfalls of test conditions***

Despite the advances of the current information age, the geographical conditions and meteorological environments in which individual persons actually use the products, and especially with regard to consumer products, the individual products are placed in local environments, and so we realize that the supplier of the product absolutely cannot confirm all these actual usage conditions. We can conjecture a wide variety of environments in various locales in different countries, including both artificial and natural environments. To use an extreme example, even the north and south polar regions do not always have cold winds and blizzards. Because of this, even equipment and instruments used in those regions are not necessarily always exposed to their symbolic environment. For example, inside places such as well-managed rooms for air conditioning facilities and inside unexpectedly humid living quarters, products are operated in local environments entirely unrelated to the polar environment.

First of all, I would like to discuss a few occasions of failure that we have experienced. These factors illustrate occurrences that were caused by a total lack of grasping the situation in countries where our products were sold. (The examples are somewhat dated, but please be patient.)

### **5-1 Fungus occurrence caused by lack of clearly understanding the transportation situation**

A little more than ten years ago, many circumstances were probably a good bit different than now. At that time, products for overseas markets were basically packed in semi-hermetically sealed packing. Before shipping products from the factory, residual moisture was removed from such sources as test chambers inside test equipment and water distribution pipes. First, products were dried by ventilation with dry air, and then moisture absorbents were placed at various sites and the products were wrapped in plastic bags and finally placed in wooden crates.

Products were shipped by air in urgent cases, but when delivery time permitted, products were sent by sea. The case we shall consider here involved air delivery to Stockholm, Sweden during summer to autumn. (The products cannot be considered to be isolated from the outside world. Basically the plastic is permeable to air, and we also cannot say that cracks did not exist. Therefore, the packing method cannot be considered appropriate to shipping involving long periods of time.)

While products were uneventfully arriving at the destination and we imagined everything to be all right, suddenly complaints began to fly. We were told that the products “smelled moldy”. At first, we didn’t understand how inorganic products could be “moldy”. Perhaps the Scandinavian fastidiousness for cleanliness was to blame.

Setting aside such speculations, I flew over empty handed. When I arrived to see for myself, I found that some products had become damp — especially those wrapped with glass wool for thermal insulation — and “smelled moldy” and had a “green mold” adhering to the packing material. (I no longer remember the name of the mold.) Of course it “smelled moldy”. Setting aside the investigation into the cause, since I had arrived empty handed, I went with the local staff for a tour of the Stockholm tool shops, purchased some tools, found an air-conditioning materials shop and purchased some insulation materials. Then, I disassembled the equipment at the customer’s location and carried out the required procedures. Some smell still remained, but it was at a bearable level. Naturally, we also had to pay a penalty.

After returning to Japan, I investigated the processes from packing up to shipping. The results showed:

- 1) When shipped from the factory, the product was determined to be dry and to have ample moisture absorbent.
- 2) There was no problem with the combination of the plastic packing and the moisture absorbent.
- 3) The wooden crate packing was not done in house, instead relying on another company to provide that service. Accordingly, that company’s service was also subject to the investigation, and we determined that they were following procedures more or less as outlined.

That left us with the question as to what could be the cause of the defect. In fact, the source of the problem was found to lie in the wooden crate material and the transportation conditions.

- 1) First, let’s look at the wooden crate material. Naturally, the crates were made of wood, but this wood was a product imported from Southeast Asia. (Indeed, by that time, there were probably already no domestic wood products suitable for use in packing materials.) The required management processing had been done, but that the results had come from less-than-thorough processing was made abundantly clear by the discovery of mold and nematodes inhabiting the packing materials of other products during the same time period. In short, the processing standards for imported materials at that time were very weak in regard to materials for Southeast Asia. The living organism that had slipped through this process gateway was able to multiply under a certain combination of conditions. Therefore, we can assume that the presence of nematodes indicates that the adhering mold spores were able to breed and multiply.
- 2) On the other hand, the transportation conditions were those of air freight, and so we had assumed (without checking) that the product would be traveling directly to the destination in a short period of time. However, while the product had been transported directly to the

Amsterdam airport, it had had to stay in Amsterdam until enough freight had accumulated to fill a large cargo flight to Stockholm, Sweden. In other words, the product had spent days exposed to airport storage conditions. Naturally, the weather had become hot, it had rained and been foggy, and so moisture penetration inside the wooden crates was not at all strange. (In other words, for the function of the moisture absorbents, the somewhat low pressure inside the plastic may have been doing more harm than good.) At any rate, we could presume that this had produced just the right environment for the mold to breed.

The source of the problem given above in section 1) combined with the factors in section 2) to produce a situation in which the mold was able to breed and spread to the thermal insulation material of the product.

To summarize what this example illustrates:

- (1) The cause should be weeded out in the beginning.
- (2) Data and current conditions for the required local environments should be checked.
- (3) Incomplete management processing can do more harm than good.

## **5-2 Metal rust occurrence caused by not learning about the local environment**

Here is another example of problems caused by not learning about the local environment.

The product in question is an incubator with a water jacket that doubles as an inner chamber wall and a thermal barrier. The product was constructed with a double inner tank wall, and the space between the walls was filled with water. Either distilled water or ion exchange water could be used, and this was written in the instruction manual. This product was delivered to a research laboratory in Switzerland. Before long, we received a complaint that water was leaking from the inner wall.

When we retrieved the item for observation at the warehouse of the local sales company, we did find traces of water leakage. Since the walls were entirely of stainless steel, the shelf supports had also been made of stainless steel and installed with electrical spot welding. And yet, wasn’t there a rough, dry white powder adhering to the welding sites?

The next day, I requested our Swiss agents to obtain a laboratory analysis of the powder and the residual water. When I received the reports to take back to Japan for analysis, they revealed that the main component was salt.

Since the instruction manual clearly stated that ion exchange water should be used, naturally the user had done so, and so we surmised that the cause could be that somehow the chlorine had not been completely cleaned out of the ion exchanger. This led to the conclusion that the high temperatures at the sites of spot welding during assembly had caused severe compositional change to the materials, leading to relatively rapid corrosion around the welded areas.

To summarize the cause of water leakage from these circumstances, we find that the following types of conditions are overlapping.

- 1) First of all, although I had learned from a textbook or somewhere in my school days that from long ago in Europe, rock salt was used from the mountainous regions, I had never thought much about it. Therefore, I lacked the concept that drinking water was basically came from mineral water sources that included salt. (In fact, you will see many seniors in Europe who need canes to walk because they have bad knees. I have heard that this is a result of drinking water with a high mineral content over many years.)
- 2) Even though the maintenance of water purification equipment is not that bad, after the equipment has been in use for a while, even water that has passed through an ion exchange device may have residual salt.
- 3) The equipment was manufactured for specifications that presumed the mostly soft water conditions of Japan.

If we observe carefully, we find that products equipped with water jackets are rarely seen in Europe. Seeing the lack of such products as a marketing opportunity, we had marketed the product without fully considering the surrounding environment. It goes without saying that sales of products of that type were immediately halted.

### **5-3 A case of equipment malfunction caused by failure to consider the high altitude environment**

Ordinarily, we rarely pay attention to the details of the atmospheric pressure unless we're listening to hurricane warnings or we're reaching the summit of a high mountain. We never thought about our environmental test equipment being brought to a research laboratory over 1,000 meters above sea level. We realized that for some reason the environmental test equipment was reproducing that sort of high-altitude environment at ground level.

The product that caused the problem was HAST equipment used for running highly accelerated humidity tests, meaning that the water vapor and pressure constituted the whole of the test. At the start of the test, the equipment had atmospheric air in the chamber and humidifying water. When the door was closed, the chamber had only one port open to atmospheric pressure: a single electromagnetic exhaust valve with a small orifice. When this valve was closed, the inside of the chamber that formed the test space was totally isolated from the outside world, completely sealed off. The temperature normally used was over 110°C, and as the temperature would rise, the initial residual atmosphere would be removed along with the water vapor during the process of reaching the set conditions. When the test temperature and humidity were reached, no air remained inside the chamber, and the environment was over 100°C composed of water vapor only.

Inside the chamber, the pressure is somewhat higher than the surrounding atmospheric pressure while the exhaust valve is open, and so while this valve is open the water temperature will only rise to about 100°C. This means that the valve is closed at around 100°C, creating a completely sealed space. At this point the residual air has almost all been discharged. Then, as the humidifying water is heated further, water vapor of over 100°C is

generated, also causing the pressure to rise. This ventilation valve was controlled by a sensor mechanism that detects the humidifying water temperature (some models use a vapor temperature sensor). However, at altitudes of above 1,000 meters the boiling point is reached before the humidifying water temperature reaches 100°C. Thus, the humidifying water in the chamber all evaporates and is discharged outside the chamber through the exhaust valve before the ventilation valve can close. The heater for the humidifying water then runs with an empty pan and overheats, and finally the safety device activates to stop the equipment.

In this example, the environmental test equipment was originally intended for use at ground level. Reproducing environments in the test equipment whose functions are based on a ground-level environment that cannot be obtained within the ambient environment can cause your subconscious assumptions to become your enemy. This case was concluded by resetting the opening and closing point of the valve to a somewhat lower temperature (at a setting below 100°C).

### **5-4 Failures caused by differences in environmental substances**

These examples demonstrate a lack of feedback. Here, we shall consider only the salient points.

During the time of the Gulf War, the multi-national forces went to the deserts of the Middle East to carry out military operations using tanks. The American military caterpillar tanks are said to have become inoperable within just four days.

Quite some time ago, because MIL-prescribed Arizona desert sand could not be obtained, sand was used from the Suma Beach in Kobe, Japan to test the construction process of the sandstorm test equipment under certain conditions. Very quickly holes appeared in the plate fin coolers of the equipment. I have also heard that the bulldozers of a certain heavy equipment manufacturer experienced similar problems in the Arabian region. Even simple desert sand can differ greatly from place to place.

To digress somewhat, with products for export and with products that are brought to other locales, lack of thorough knowledge about the various environments of the region can cause absurd failures. Sometimes the conditions of the local environment must be seen to be understood. For example, even with the various international standards, we cannot always feel confident simply because a product has cleared the test standards as they are written. (Indeed, it is not written anywhere in these standards that "running tests using these test methods provides a total guarantee of the product".) Confidence can only be acquired by accumulating experiences of failure.

We now live in an age that is going digital and visual. A little effort goes a long way toward obtaining a wealth of information on environments all over the globe. Acquiring such information is becoming easier every day. For example, international information can be found using such sources as newspapers, magazines, travel brochures, and TV news and documentaries. In such cases, judgement is not merely based on personal observation. I believe that to avoid overlooking environmental sub-

stances, one must develop the habit of looking at the details for oneself, grasping them, thinking about them, and forming images.

## 6. Conclusion

This article has discussed a wide variety of factors involved in environmental testing. As far as possible, I have tried to take up matters that you will not find in general references on reliability. Perhaps the focus has been on psychological factors, but as a writer, this is as far as I can go. Filling in the details is your job.

We have taken up all the test methods found in the IEC 60068 Series that consists of representative environmental test standards, and currently no specific proposals have been put forth for test methods with new standards. Furthermore, manufacturers are not very fond of presenting failure analysis based on examples of failure, and so you will not often find published references or lectures and symposiums based on such examples. The only way to accumulate such information is to do it on your own.

We can no longer say that looking at cost and resources will suffice to determine whether to run all of the tests affecting the product. During the research and development stages as well, many questions remain as to whether all hypothetical test items must be run.

Now, let's summarize the key points of environmental testing

- (1) Knowing just when to 1) avoid work is crucial. Surely this constitutes part of modern job know-how, and is a key point. (A basic sense of logic is required, and an overly subordinate attitude of following the rule book is not really very bright.) You have to put on your thinking cap. A little intelligence is needed. Being able to carry this off requires 2) a background of basic knowledge and education. Using how-to methods for people in a hurry cannot give you that background.
- (2) However, if you have routine duties for running clear-cut environmental tests, you need only follow the existing manual. The job is not improved by considering unnecessary items. (Nowadays, if the subdivision of duties has advanced to the point of making a cut-and-dried process, that is sufficient.) Sometimes, what is unnecessary is clearly unnecessary.
- (3) Running into difficulties can take a lot of time, but basic education and 3) accumulated experience can round out environmental test technology. However, we must not forget that this technology, along with developing peripheral technology, is in constant transition (including becoming out-of-date).
- (4) While this may go without saying, the what this article means by "basic education" concerns linguistics, mathematics, physics and chemistry. If possible, a background in technology is also helpful. (This

represents my own personal opinion.)

I hope that this article will give you a fuller knowledge of environmental testing technology and prepare you for handling the basic methods.

Although these are not key points, let's also consider urgent problems in environmental test technology.

- (1) It is of vital importance to pass on to the next generation environmental test technology that has been accumulated as varied technological experience. Somehow, we must recognize the importance of converting the hidden information known as know-how and individual technological aspects to concrete information and passing this information on to our successors.
- (2) At present, software has not yet been developed that can include all environmental test items, but in the near future when simulation technology for analytical evaluation is established that can use details of past data and construct theories, we should be able to run "virtual tests". All of the roles played by current test methods directly using all types of environmental test equipment will slowly but surely disappear.

As we enter the age of low birth rates, it will become more and more difficult to solve problems with labor-intensive methods. Even now, policies are being boldly carried out to improve human education, and we must consider nurturing human abilities that can achieve the maximum state of the art.

Finally, living, breathing humans are the real focus of activities to plan and run environmental tests that maintain the reliability of products, even when the subject of those activities are inorganic industrial products, so don't forget that you play an important role.

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### [Bibliography]

- 1) NASA Preferred Reliability Practices Environmental Factors Practice No.PD-EC-1101

# Evaluation results on reliability of lead-free solder —Tabai Espec efforts to develop viable lead-free solder—

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*As the amount of discarded products from our modern life-style continues to increase, concern has arisen over toxicity to humans from lead leaching out of solder from home appliances and automobiles. Society is becoming aware of the pressing need to eliminate this toxic substance from our products by creating a viable lead-free solder. We at Tabai Espec have undertaken the challenge of creating lead-free solder for use in PCB's to protect the environment. Setting out to obtain basic selection data for the various types of lead-free solder, we have evaluated mounting and reliability of lead-free solder for both reflow soldering and flow soldering. Our results show that the solderability of lead-free solder is inferior to conventional solder, and that for lead-free solder, more study is needed on temperature control in the mounting process as well as on surface treatment of parts.*

## 1. Introduction

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Solder is used as a joining material in printed circuit boards (PCB's) used in discarded home appliances. Concern has arisen over the toxicity to humans from lead leaching out of that solder and into the underground aquifer. Global progress is being made in research on the development and adoption of lead-free solder.<sup>1), 2)</sup>

In Japan, the lead-free evaluation project "Research and development of lead-free solders toward practical solution and standardization" was completed in March 2000 as a consignment project for NEDO (the New Energy and industrial technology Development Organization). The report on the results of that research published findings on mounting processes and mounting characteristics suited to the special characteristics and practical application of the various types of lead-free solder. The report assumes a role of global leadership in promoting the adoption of lead-free solder.

Meanwhile, the fourth draft of a directive proposing the collection and reuse of electrical and electronic parts (WEEE directive: "Proposal for a directive on Waste from Electrical and Electronic Equipment") was published in the EU (European Union) in May 2000. The EU plans to regulate the use of leaded solder from January 2008.

Bills to enact laws regulating the use of leaded solder were studied in the US in 1990, but the US is not currently moving toward regulation. However, research and development for the adoption of lead-free solder was carried out for four years from 1994 by the NCMS (National Center for Manufacturing Sciences), and the NEMI (National Electronics Manufacturing Initiative) began activities in the year 2000. Developments are now under way for promoting the global adoption of lead-free solder.

We at Tabai Espec as well have taken up the challenge of developing lead-free solder for PCB's as a means of reducing the burden on the environment. To promote the use of lead-free solder, we must evaluate reliability of the various types of lead-free solder to obtain basic selection data.

This report presents the results of our studies at Tabai Espec concerning the results of mounting evaluation and reliability evaluation for reflow soldering<sup>\*1</sup> and flow soldering using lead-free solder, and compares this with conventional Sn-Pb eutectic solder. The report also looks at reliability problems encountered when using lead-free solder.

## 2. Tabai Espec efforts to develop viable lead-free solder

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Table 1 shows Tabai Espec activities for the adoption of lead-free solder. Promoting the adoption of lead-free solder requires a high level of scholarship and a serious commitment of time. We at Tabai Espec are participating in the national cooperative "R&D of lead-free solders toward practical solution and standardization". We have also established our in-house "Committee to promote lead-free solder" and set up a site for information exchange between related departments such as production groups and technology groups to study the issue of adopting lead-free solder for use in PCB's. Evaluation methods have been divided into two stages, primary evaluation and secondary evaluation. For primary evaluation, we first produce special-purpose evaluation PCB's for selecting lead-free solder, and we use these PCB's to evaluate reliability and mounting workability. Next, we use actual product PCB's to evaluate the reliability of the lead-free solder selected in the primary evaluations, field test them, and based on those evaluation

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\*Environmental Test Technology Center

results, we plan to promote the adoption of lead-free solder for successive products targeting the year 2001.

**Table 1 Tabai Espec activities for the adoption of lead-free solder**

Activities	Aims	Schedule			
		1998	1999	2000	2001
1. Participation in the NEDO "Research and development of lead-free solders toward practical solution and standardization"	<ul style="list-style-type: none"> <li>Cooperative research</li> <li>Standardized test methods</li> </ul>		→		
2. In-house establishment and activities of the "Committee to promote lead-free solder"	<ul style="list-style-type: none"> <li>Sharing and dispatching information</li> <li>Proposing development of evaluation devices</li> </ul>		→ Monthly meetings		
3. Primary evaluation using special-purpose PCB's	<ul style="list-style-type: none"> <li>Mounting and reliability evaluation</li> <li>Selecting lead-free solder</li> </ul>		→ Solder selection		
4. Secondary evaluation using product PCB's	<ul style="list-style-type: none"> <li>Developing mounting technology</li> <li>Evaluating reliability</li> </ul>		→ Mounting evaluation	→ Field evaluation	
5. Adopting lead-free solder for products	<ul style="list-style-type: none"> <li>Developing products</li> <li>Reducing environmental burden</li> </ul>			→ Successively adopting lead-free products	

### 3. Evaluation results for reflow soldering, and evaluation results for insulation reliability

#### 3-1 Using special-purpose PCB's to evaluate mounting characteristics

##### 3-1-1 Evaluation solder and mounting conditions

Table 2 shows lead-free reflow soldering materials selected in the primary evaluation. The solder selected, according to currently published data, is basically composed of Sn-Ag materials, with Cu (copper) added to improve solderability and Bi (bismuth) added to lower the melting point.<sup>(5)</sup> The following items were considered in making the selection.

- 1) Confirmation of the above-average reliability of conventional Sn-Pb eutectic solder
- 2) Possibility of using pre-existing equipment (can be mounted in open air atmosphere)
- 3) Confirmation of workability
- 4) Procurement of materials (Even with different types of solder such as paste, rod, and string solder, the same materials can be procured.)
- 5) Cost

Conventional Sn-Pb eutectic solder was also used in these experiments as a standard for comparison. Cost studies were carried out on Sn-Cu (tin-copper) and Sn-Zn (tin-zinc), but we decided to put the matter off due to workability problems and due to the fact that pre-existing equipment cannot be used with the current situation here at Tabai Espec. We plan to investigate these solder materials if future improvement is seen in these areas.

**Table 2 Types of lead-free solder selected**

	Solder type (mass %)	Melting point (°C)
1	Sn-3.5Ag	221
2	Sn-3.5Ag-0.75Cu	216 to 220
3	Sn-2Ag-0.75Cu-3Bi	205 to 218
4	Sn-37Pb (reference)	183

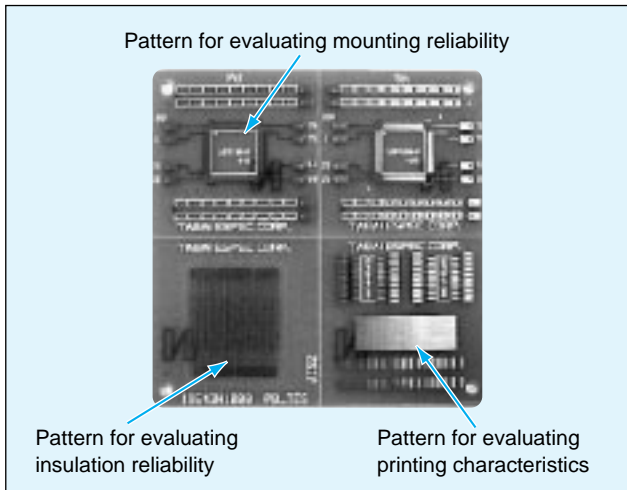
Next, we produced an evaluation PCB for the purpose of evaluating mounting and evaluating reliability (Photo 1). The evaluation PCB was produced to study 1) items for evaluating workability and mounting characteristics, including solderability, printing characteristics, solder bridging, and the Manhattan phenomenon (chip build-up), and 2) items for evaluating reliability, including comparison of plating of parts, joint reliability, and insulation reliability. Glass cloth epoxy (FR-4 equivalent) was used as PCB material, and the PCB measured 100 mm square and 1.6 mm thick. Specifications called for V-cuts in the PCB so that it could be snapped into four pieces for ease of investigation during evaluation and analysis.

**Table 3 Items for evaluating mounting characteristics, and evaluation details**

Evaluation items	Evaluation details
Solderability	Radius and height on PCB to which specific quantity of solder spreads
Printing characteristics	Printing Ease of workability, paste feed, how little seepage occurs
Solder bridging	Number of places neighboring terminals connected with solder
The Manhattan phenomenon	Number of chips composing vertical build-up

To evaluate connection reliability, a 100-pin QFP package<sup>\*2</sup> was mounted using an internal daisy-chain connection<sup>\*3</sup>, and set up for ease of measuring changes in contact resistance due to solder degradation. In addition, to evaluate plating of QFP leads, both Sn-Pb (Sn-10Pb) plating and Pd (palladium) plating were used. Other mounted parts included 2012 type<sup>\*4</sup> chip resistance (0Ω) multiple linked connections and a 20-pin SOP package<sup>\*5</sup>.

A JIS2 type equivalent comb pattern (pattern intervals 0.318 mm) was used to evaluate insulation, and a JIS-Z-3284 specified pattern was used to evaluate printing characteristics and solderability.



**Photo 1 PCB for evaluating reflow soldering**

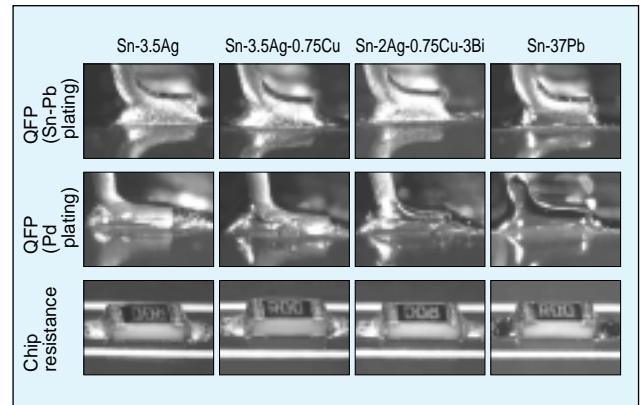
### 3-1-2 Evaluation results for mounting

Based on solder manufacturer data, mounting results were studied and determined for reflow soldering temperature profile settings. Pre-heating temperature for conventional solder is set at approximately 155°C, and the peak temperature is set at approximately 225°C.

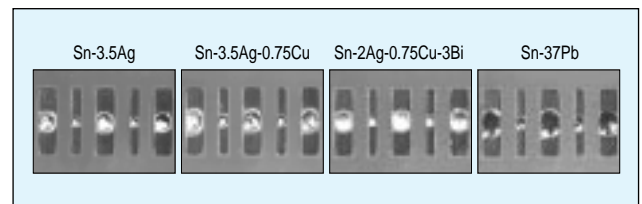
Those temperature conditions are 10 to 15°C higher for lead-free solder, with pre-heating targets set at 165°C and peak temperature targets set at 240°C.

Photo 2 shows the soldered areas for part leads after mounting for the different conditions. Conventional solder shows good wetting for each part, but the lead-free solder with QFP package Pd plating shows poor wetting build-up. The Sn-3.5Ag wetting build-up is particularly bad, and this is thought to be due to its having a melting point higher than the other types of lead-free solder.

Photo 3 shows the results of solder wetting for a copper-plated PCB. Conventional solder has a large area of wetting with a build-up of spread solder to 0.05 mm (n = 20). On the other hand, lead-free solder has a build-up to 0.1 mm with poor spreading. The poor results are thought to stem from the characteristics of the main component of lead-free solder (Sn), as a coating of tin oxide forms and seems to affect the wetting characteristics. Using a reflow process in a nitrogen atmosphere is considered to be an effective method for improving solderability.



**Photo 2 Appearance after mounting**



**Photo 3 Solderability results (after reflow soldering)**

## 3-2 Reliability testing

### 3-2-1 Test methods

Reliability tests for soldered joints were used to evaluate joint reliability and insulation reliability. Using thermal shock (temperature cycle) tests and heat (creep) tests, the main failure modes seen during evaluation for joint reliability were (1) thermal stress failure due to temperature cycles, (2) creep failure due to uniform stress and temperature, and (3) degradation of the solder itself due to temperature assumed to be caused by heat fatigue (e.g., due to metallic diffusion and the growth of intermetallic compounds).

Generally when using temperature and humidity tests, the main failure modes for insulation reliability were (1) insulation degradation due to flux in the solder paste, and (2) degradation thought to be related to water adsorption such as insulation degradation due to the occurrence of ionic migration.

### 3-2-2 Evaluation methods

Methods for evaluating heat fatigue of soldered joints include (1) visually evaluating cracking of soldered joints (external appearance and cross-section observation), (2) measuring changes in conductor resistance, and (3) measuring residual joint strength using a tensile strength test (or pull test). Leadframes such as QFP are pulled upward at a uniform speed at an angle of 45 degrees relative to the PCB as shown in Fig. 1, and the maximum load at the point of rupture is measured.<sup>4)</sup> Other methods for evaluating insulation degradation include observing the external appearance of PCBs with comb patterns and measuring changes in insulation resistance during the tests.

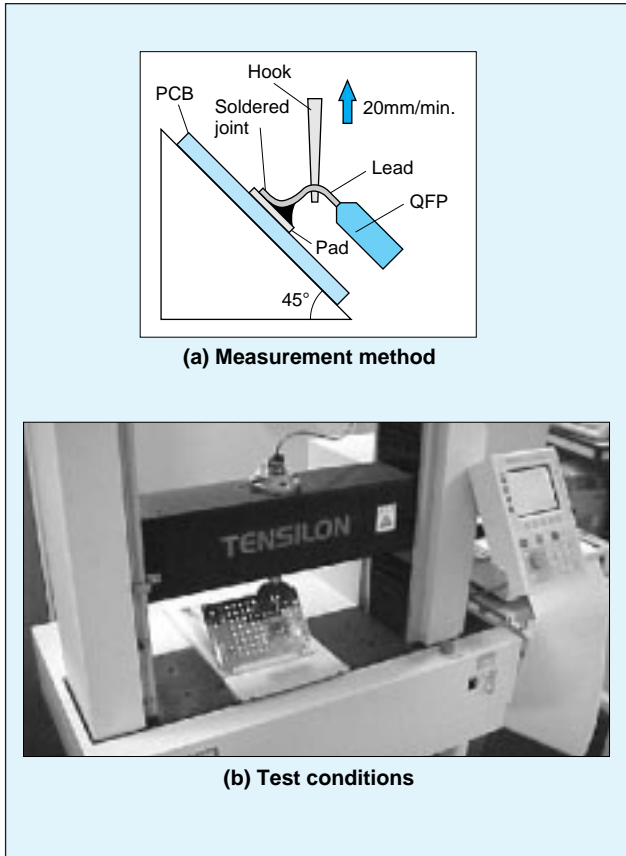


Fig. 1 Measuring tensile strength

**3-2-3 Test conditions**

Table 4 shows the items and conditions in reliability tests. The tests and their related aims covered the following areas. (1) The thermal shock (temperature cycle) tests were used to evaluate deformation in soldered joints caused by differences in coefficients of thermal expansion in the various structural parts. (2) The high-temperature tests were used to evaluate creep fracture caused by heat and metallic diffusion and the growth of intermetallic compounds. (3) High-temperature and high-humidity tests were used to evaluate migration characteristics and flux insulation degradation. Photo 4 shows the test equipment and the system appearance.

**Table 4 Reliability test items and conditions**

Test items	Test conditions	Evaluation items	Equipment used (all made by Tabai Espec)
Thermal shock test (temperature cycle test)	-40°C ↔ +125°C Dwell time 30 min. 1,000 cycles	<ul style="list-style-type: none"> <li>Changes in conductor resistance</li> <li>Tensile strength</li> <li>Observation of cross-section and external appearance</li> </ul>	<ul style="list-style-type: none"> <li>Thermal shock chamber TSA-100S-W</li> <li>Printed wiring board conductor resistance evaluation system AMR-280P</li> </ul>
High-temperature test	+125°C 1,000 hours	<ul style="list-style-type: none"> <li>Changes in conductor resistance</li> <li>Tensile strength</li> <li>Observation of cross-section and external appearance</li> </ul>	<ul style="list-style-type: none"> <li>Temperature chamber (Industrial oven) PHH-200</li> <li>Printed wiring board conductor resistance evaluation system AMR-280P</li> </ul>
High-temperature and high-humidity test	+85°C, 85% RH 50 V DC applied 1,000 hours	<ul style="list-style-type: none"> <li>Changes in insulation resistance</li> <li>Observation of external appearance</li> </ul>	<ul style="list-style-type: none"> <li>Ultra-low temperature and humidity chamber PSL-2</li> <li>Ionic migration evaluation system AMI-050-P</li> </ul>

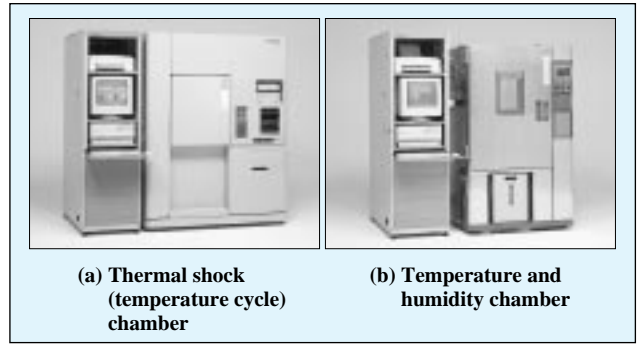


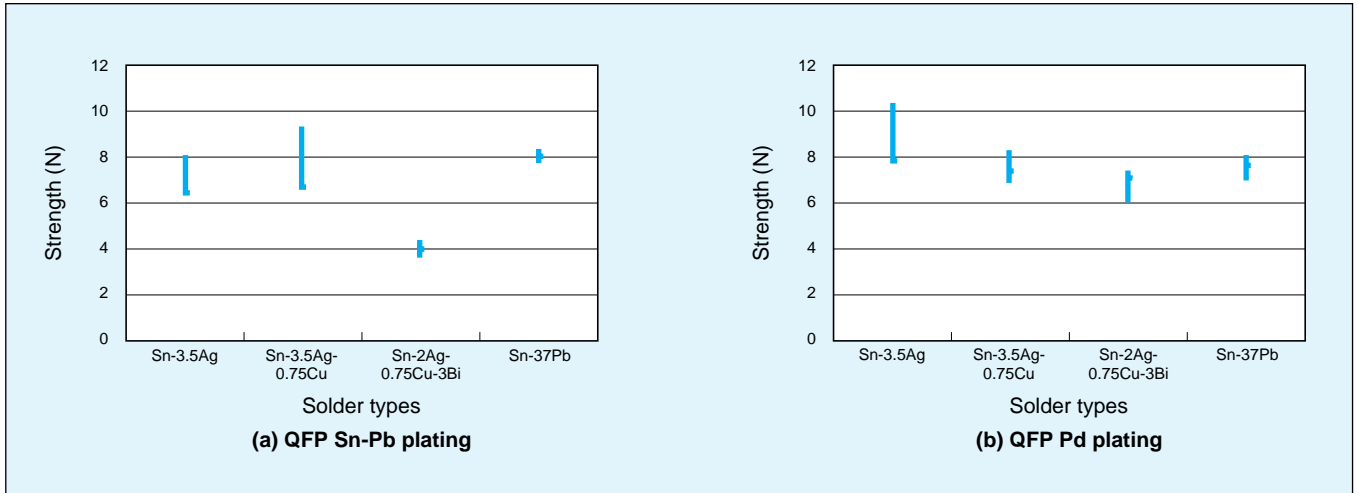
Photo 4 Test equipment

**3-3 Results of reliability evaluation**

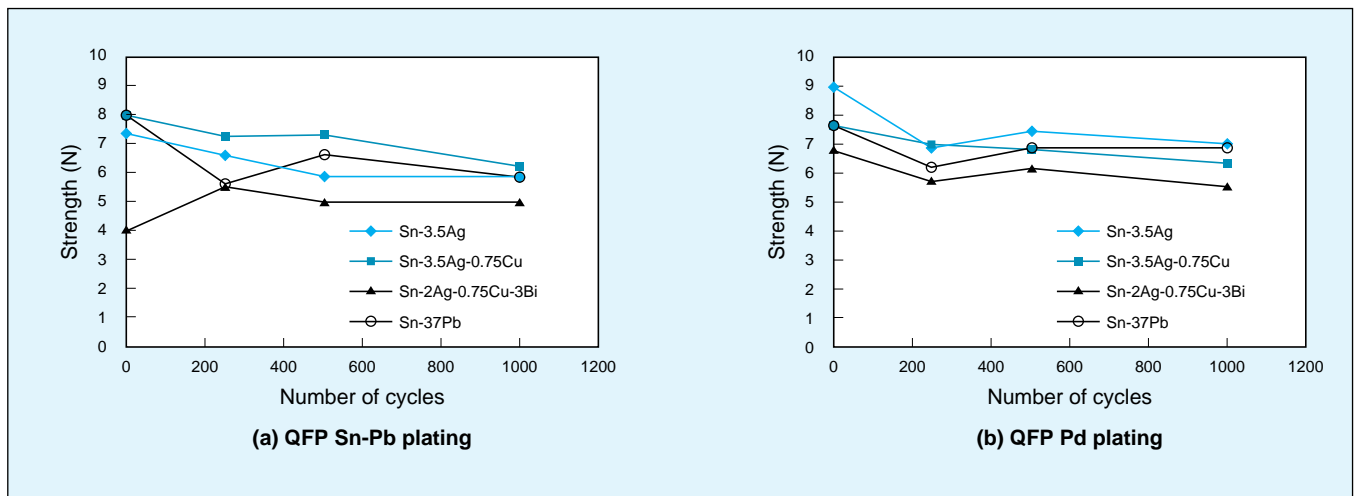
**3-3-1 Results of tensile strength characteristics**

Fig. 2 shows the measurements of initial tensile strength for the Sn-Pb-plated and Pd-plated QFP leads. With the Sn-Pb plating, the Sn-3.5Ag and the Sn-3.5Ag-0.75Cu both showed joint strength tendencies equivalent to or greater than the Sn-37Pb, while plating that included Bi (Sn-2Ag-0.75Cu-3Bi) showed a tendency toward a relative loss of strength. Also, lead-free solder showed more variability in strength than Sn-37Pb, and this is thought to be a result of the solderability of the solder on the leads. On the other hand, Pd plating, including that using Bi (Sn-2Ag-0.75Cu-3Bi) did not show a greater loss of strength than Sn-Pb.

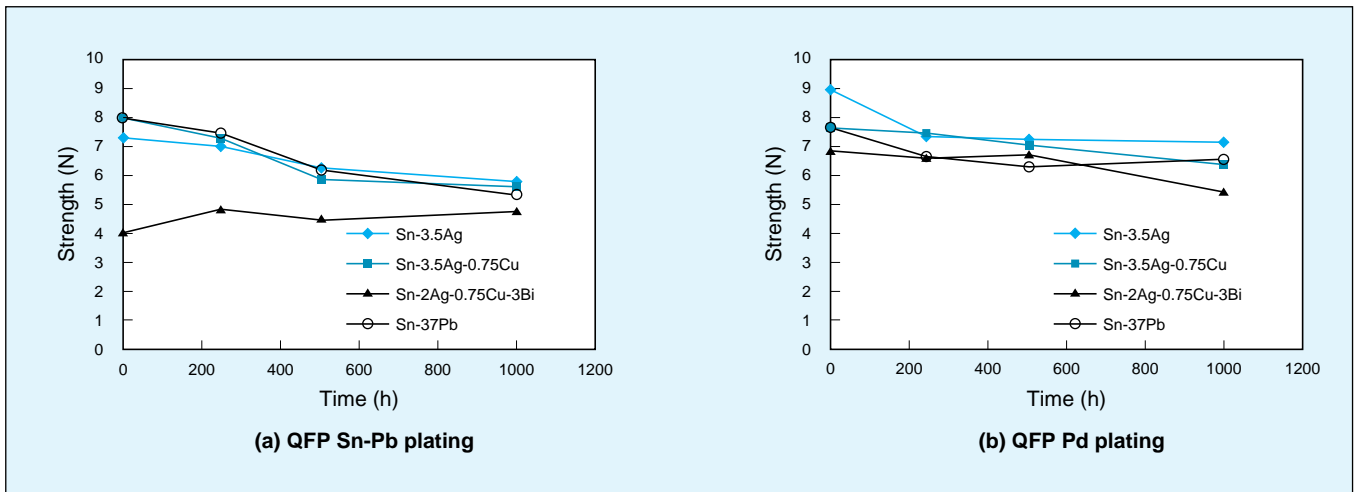
Fig. 3 shows the changes in strength during the thermal shock test, and Fig.4 shows the changes in strength during the high-temperature test. The Sn-3.5Ag and the Sn-3.5Ag-0.75Cu both evidenced similar tendencies of strength loss as the Sn-37Pb in thermal shock tests and high-temperature tests, but the Sn-2Ag-0.75Cu-3Bi showed a greater tendency for strength loss than the Sn-37Pb. The strength loss was especially large in the Sn-Pb plating, and other than the brittleness of the Bi itself, this is assumed to be due to the effects of “low-melting eutectic” with Pb.<sup>5), 6)</sup>



**Fig. 2 Initial tensile strength**



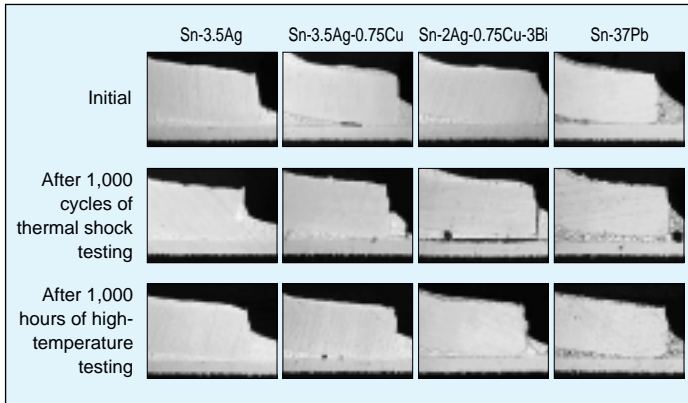
**Fig. 3 Changes in tensile strength after the thermal shock test**



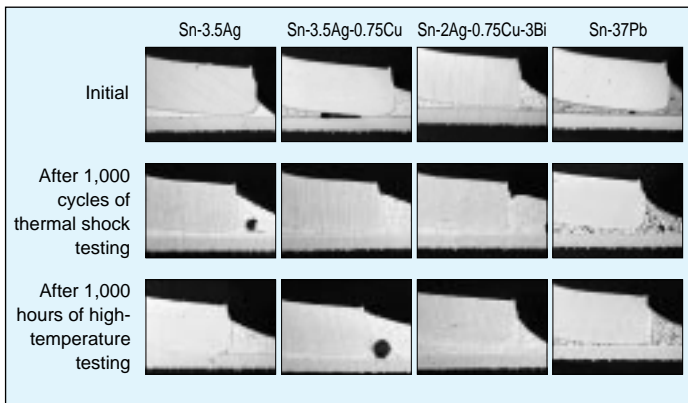
**Fig. 4 Changes in tensile strength after the high-temperature test**

### 3-3-2 Results of cross-section observation

Photos 5 and 6 show initial cross-section observation for Sn-Pb plating and Pd plating on QFP leads and observation after 1,000 cycles of thermal shock (temperature cycle) testing and after 1,000 hours of temperature testing. A finer crystalline structure can be confirmed for lead-free solder than the Sn-37Pb solder in the initial condition. Also, there are a comparatively large number of voids.<sup>6</sup> The reason for the increase in voids is not yet clear, but it is thought to be related to the temperature rise and drop rates during reflow. This must be investigated further.



**Photo 5 Results of cross-section observation of QFP leads (Sn-Pb plating)**



**Photo 6 Results of cross-section observation of QFP leads (Pd plating)**

After each test was concluded, the Sn-3.5Ag and the Sn-3.5Ag-0.75Cu evidenced no recrystallization of structure, and no growth of intermetallic compounds, and were not in a condition leading to cracking. On the other hand, the Sn-2Ag-0.75Cu-3Bi had cracks occurring at the lead connection interface with Sn-Pb only. The Sn-37Pb was not in a condition leading to cracking, but showed progressive recrystallization of the solder structure, which presumably would eventually result in cracking.

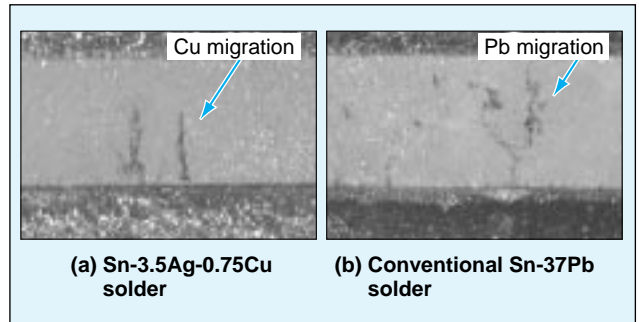
Recrystallization of the solder structure was not seen in the lead-free solder because of the formation of stable compounds due to the fine dispersion of the Ag<sub>3</sub>Sn. Also, there is almost no solid solution of Ag in the Sn, and so once the Ag<sub>3</sub>Sn has formed, reports indicate that it does not become coarse even when exposed to high temperatures.<sup>7), 8)</sup> Sn-2Ag-0.75Cu-3Bi shows conditions leading to cracking with Sn-Pb plating, presumably because (just as with the tensile strength characteristics) the lead

interface may have had a Sn-Pb-Bi low melting point alloy eutectic phase (melting point 99.6°C) which could have impeded the interface reaction to maintain Pb strength.<sup>6), 9)</sup> When using solder with Bi, care must be taken to prevent mixing in Pb from the plated lead parts.

### 3-3-3 Evaluation results for insulation reliability

The insulation evaluation methods used for both reflow and flow soldering<sup>7)</sup> were based on the JIS2 type comb pattern PCBs (conductor intervals: 0.318 mm; medium: glass cloth epoxy; electrodes: copper plating), and four types of solder (Sn-3.5Ag, Sn-3.5Ag-0.75Cu, Sn-2Ag-0.75Cu-3Bi) were used to evaluate reflow soldering. RA flux was used on the comb-pattern electrodes for soldering.

Fig. 5 shows the insulation evaluation results for each type of solder. All solder types showed a drop in insulation resistance during the tests. Post-test observation of external appearance and elemental analysis revealed the occurrence of Cu (copper) ionic migration in the lead-free solder (Photo 7(a)). Conventional Sn-37Pb solder experienced ionic migration of its main component, Pb (Photo 7(b)).



**Photo 7 External appearance after testing**

The sites of Cu migration occurring due to the use of lead-free solder come from the areas not coated by solder. This lack of complete coating is thought to stem from the poor solderability of lead-free solder, resulting in Cu migrating from the substrate metal. On the other hand, conventional Sn-37Pb solder exhibits good solderability on the copper-plated electrodes, providing a good coating on the electrodes, presumably the reason that Cu migration does not occur. With Sn-37Pb, migration originates instead from a component of the solder material.

The migration characteristics of each type of solder material were re-evaluated using a water drop method consisting of uniformly dripping ion exchange water on the electrodes. Evaluation results found a tendency for Pb migration to occur within a short time using conventional Sn-37Pb, while the tendency seen with lead-free solder was to take longer for migration to appear, and the migration component was identified as Sn (Photo 8). The exposed surface of the solder becomes covered with an oxidized film. Unlike conventional Sn-37Pb solder, the main component in lead-free solder is Sn, which forms a more stable oxidized film than Pb. This more stable oxidized film is thought to make lead-free solder somewhat more resistant to migration.<sup>10), 11)</sup>

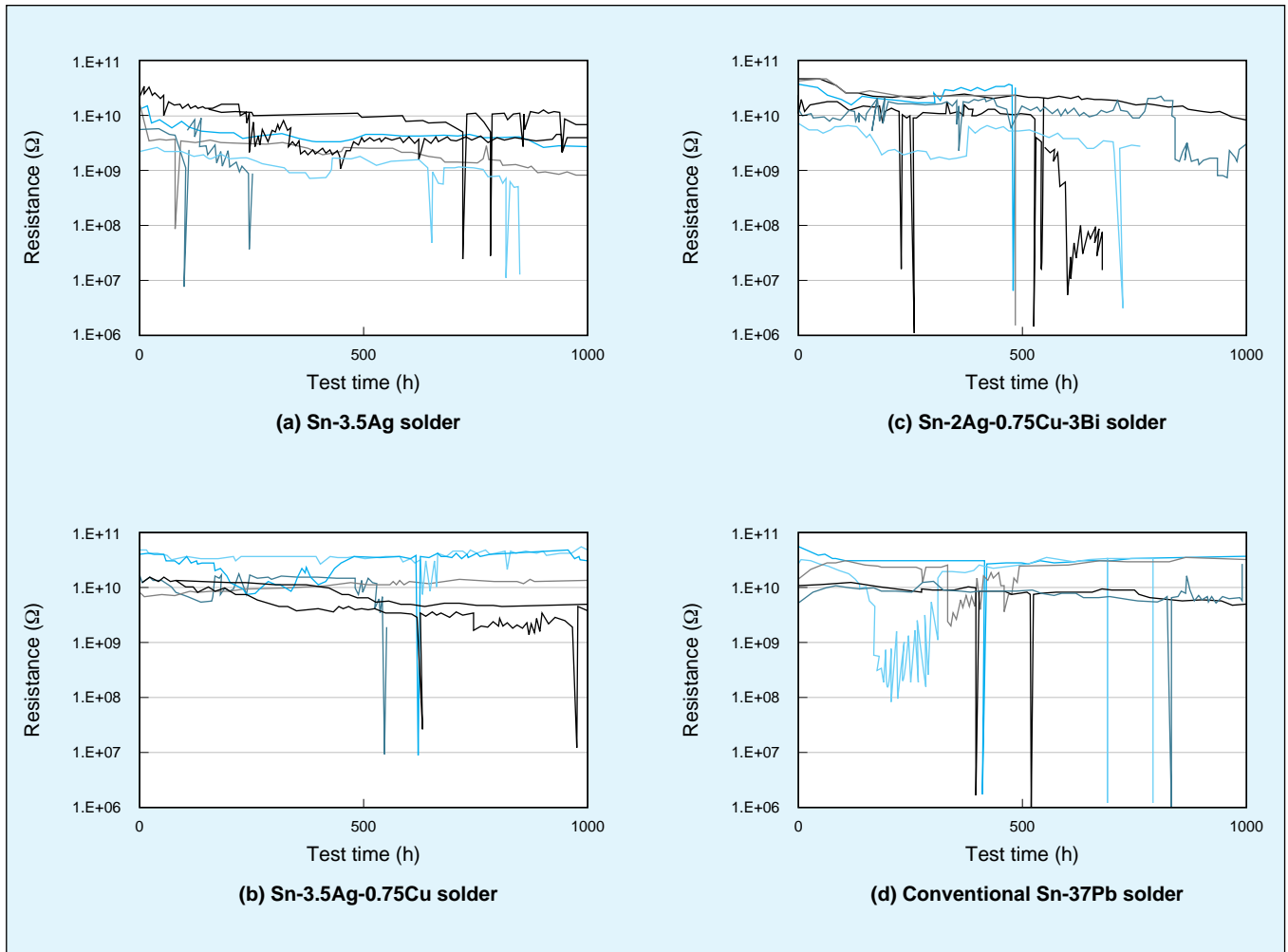


Fig. 5 Insulation resistance measurements (n = 10, only one portion of graphs shown)

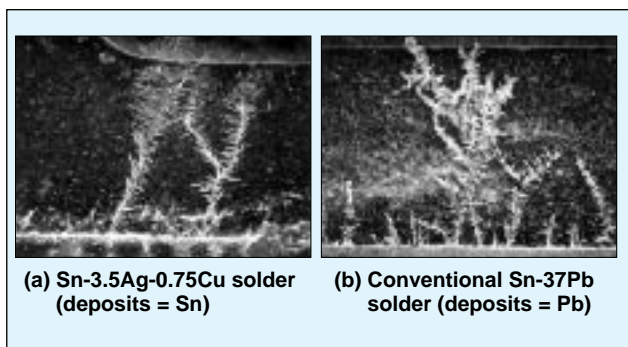


Photo 8 Migration caused by water drop method

## 4. Evaluation results for flow soldering

### 4-1 Evaluating PCBs and mounting characteristics

#### 4-1-1 Solder used for evaluation, and mounting conditions used

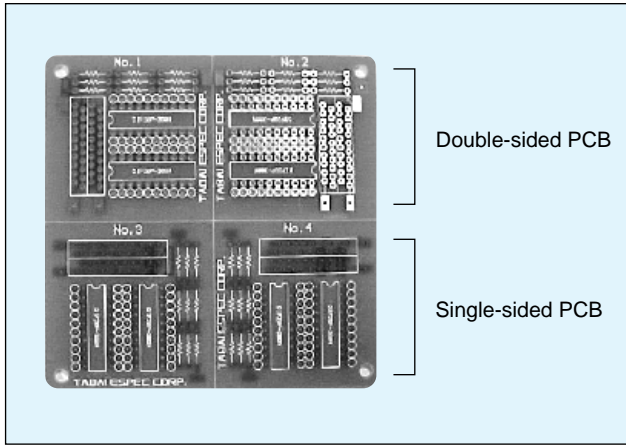
Table 5 shows the composition of the lead-free solder types used to evaluate flow soldering. The same solder types were selected as those used to evaluate reflow soldering. The main component Sn-Ag was used with either Cu (copper) or Bi (bismuth) added, and conventional Sn-37Pb was used as a standard for comparison. Due to difficulties in obtaining the solder with the Bi component, the solder used in these tests contained 0.25 mass percent less Cu and 1 mass percent less Bi than that used for reflow soldering tests.

Table 5 Solder for flow soldering evaluation

	Solder type (mass %)	Melting point (°C)
1	Sn-3.5Ag-0.75Cu	216 to 220
2	Sn-2Ag-0.5Cu-2Bi	210 to 222
3	Sn-37Pb (reference)	183

Photo 9 shows an evaluation PCB used to evaluate reliability and mounting characteristics. Glass cloth epoxy (FR-4 equivalent) was used as PCB material, and the PCB measured 100 mm square and 1.6 mm thick. A DIP type IC package (2.54 mm pitch width,  $\phi$  1.0 mm) was used as a mounted part, with connectors (2.54 mm pitch width,  $\phi$  0.8mm) and resistors (10 mm pitch width,  $\phi$  0.9 mm). PCBs with double-sided through-hole patterns and PCBs with single-side patterns were created for use with the different parts.

The flow soldering mounting conditions for the lead-free solder were 110°C pre-heat temperature and 240°C peak temperature, approximately 10°C higher than the 100°C pre-heat and 240°C peak temperatures employed for conventional Sn-37Pb solder. The mounting method consisted of spraying on activated rosin flux, then using the single wave jet method for applying the solder.

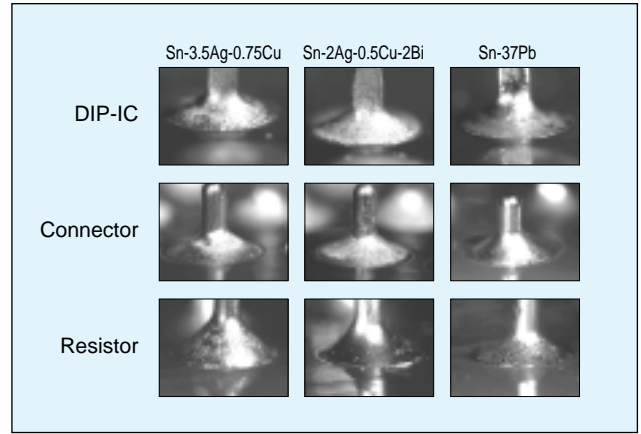


**Photo 9 PCB for evaluating flow soldering**

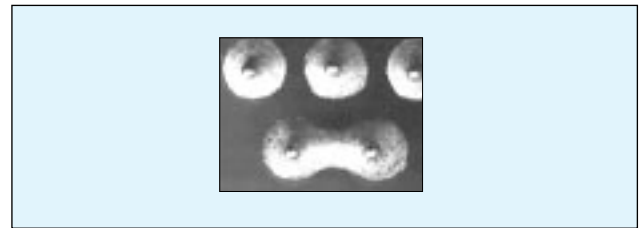
#### 4-1-2 Mounting evaluation results

Photo 10 shows the solder conditions for the parts mounted on a double-sided through-hole PCB. The lead-free solder shows good results for solderability characteristics of all mounted parts compared to conventional Sn-37Pb solder. On the other hand, a lot of solder bridging was seen to occur at the narrow pitch width of the connectors (Photo 11). This is thought to be related to the surface tensile strength of the solder at the time of fusion. Care is assumed to be required in the PCB pattern design, in the direction of soldering, and in controlling the temperature during the mounting process.

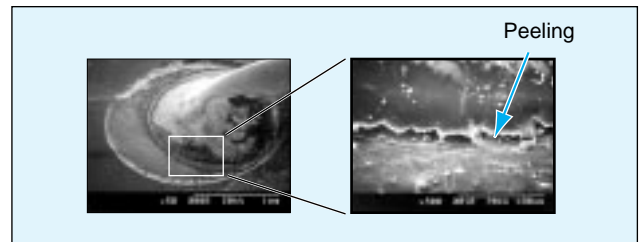
Solder containing Bi showed evidence of lift-off (fillet-lifting) on the surface of the PCB parts side (Photo 12). Lift-off refers to peeling due to segregation of Bi at the interface with the PCB land<sup>8</sup> at the time of solder hardening. Reports indicate that increasing the cooling speed during the mounting process can reduce segregation and prevent lift-off.<sup>12), 13)</sup> The Tabai Espec evaluation also found lift-off occurring only at the PCB parts side, and not occurring on the solder side. Because of this, we believe thermal capacity and thermal conductivity of the various mounted parts causes differences in hardening time, leading to lift-off.



**Photo 10 External appearance after mounting (solder side)**



**Photo 11 Solder bridging**  
(Sn-2Ag-0.5Cu-2Bi, connectors)



**Photo 12 Site of lift-off occurrence, SEM image**  
(Sn-2Ag-0.5Cu-2Bi, resistor surface)

## 4-2 Results of reliability evaluation

### 4-2-1 Test conditions

Table 6 shows test items and conditions for the reliability tests. Tests used to evaluate reliability consisted of high-temperature tests to evaluate changes in solder structure and growth of intermetallic compounds, and thermal shock tests to evaluate the strength of solder bonds under repeated stress. Evaluation items included observing cross-sections and comparing results with Sn-37Pb solder.

**Table 6 Reliability test conditions and evaluation items**

Test items	Test conditions	Evaluation items	Equipment used (All made by Tabai Espec)
High-temperature test	+125°C 2,000 hours	Cross-section observation (removed for observation during test: initial, 250 hours, 500 hours, 1,000 hours, and 2,000 hours)	Temperature chamber (industrial oven) PHH-200
Thermal shock test (temperature cycle test)	-40°C ↔ +125°C Dwell time 30 min. 2,000 cycles	Cross-section observation (removed for observation during test: initial, 250 cycles, 500 cycles, 1,000 cycles, and 2,000 cycles)	Thermal shock chamber TSA-100S-W

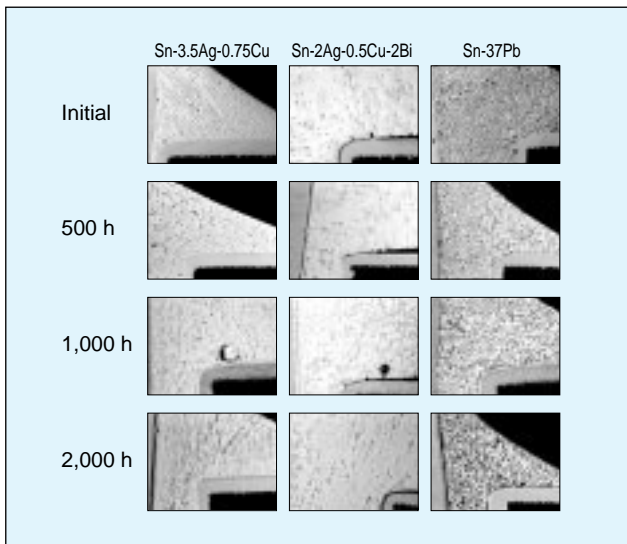
#### 4-2-2 Results of observation of flow soldering cross-sections

Photos 13 and 14 show the post-test cross-section observation results for flow PCBs. Initial conditions showed a finer structure for lead-free solder than for conventional Sn-37Pb solder. Also, lift-off was confirmed at the interface of the solder and PCB part side land with Sn-2Ag-0.5Cu-2Bi solder.

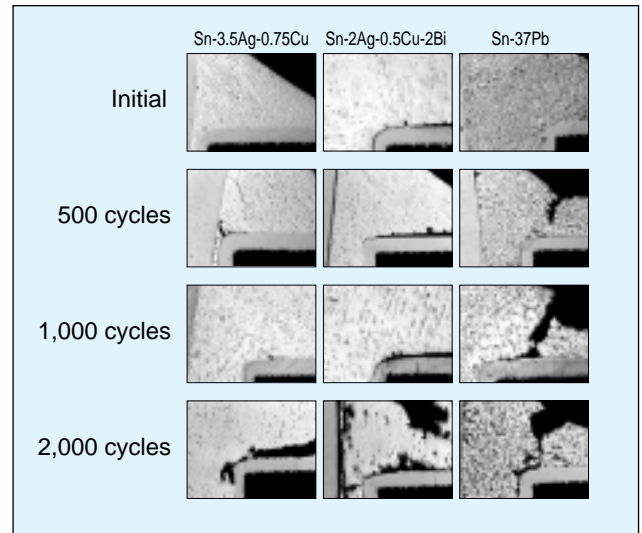
In the high-temperature tests, the Sn-37Pb solder structure became coarser after recrystallizing, but recrystallization was not seen in the lead-free solder. We postulate that, just as in the evaluation results of the reflow soldering, the stable compound  $Ag_3Sn$  forms in the lead-free solder, and once  $Ag_3Sn$  has formed, the solder does not become coarse even when exposed to high temperatures.

In the thermal shock (temperature cycle) tests, the structure of the Sn-37Pb solder became coarser when the solder recrystallized, just as in the high-temperature tests. After this solder had become coarser, cracks were generated from the solder fillet section<sup>9</sup>, and complete cracking had occurred by 2,000 cycles. No cracking was seen in the Sn-3.5Ag-0.75Cu solder after 1,000 cycles, but cracks were found at the interface between the solder and the PCB land after 2,000 cycles.

The Sn-2Ag-0.5Cu-2Bi solder suffered peeling around the interface between the solder surface and the part leads and PCB land after 2,000 cycles. No progress toward lift-off was seen after 1,000 cycles, but the interface peeling found after 2,000 cycles was believed to have been caused by lift-off.



**Photo 13 Results of cross-section observation after high-temperature testing (500×)**



**Photo 14 Results of cross-section observation after thermal shock testing (500×)**

## 5. Conclusions

The following conclusions were based on the results of mounting evaluation and reliability tests.

- (1) In the presence of thermal stress, the Sn-3.5Ag and Sn-3.5Ag-0.75Cu lead-free solder types showed equivalent or superior reliability to conventional Sn-37Pb eutectic solder.
- (2) Lead-free solder containing Bi suffered a loss of connectivity strength related to surface treatment of parts (mixing in Pb from the parts).
- (3) During flow soldering, lead-free solder containing Bi experienced lift-off (fillet-lifting) due to the difference in solder hardening time related to the thermal capacity and thermal conductivity of the parts.
- (4) Lead-free solder has a much higher resistance to migration than conventional Sn-37Pb solder due to the formation of an Sn oxidation film.
- (5) Lead-free solder has poor solderability, requiring care to prevent migration from substrate metals such as copper.
- (6) The higher solder temperatures for lead-free solder necessitates further study on heat resistance of parts.

## Terminology

### \*1 Reflow soldering

In reflow soldering, the required amount of solder is supplied in advance at the soldering sites, and this solder is then melted using a heat source such as infrared rays, hot air, hot plate, or laser to form a metallic union between both sides.

### \*2 QFP (Quad Flat Package)

The QFP is a type of IC package in which the QFP leads come out from 4 sides of the package and form a gull-wing type (L-shaped) package.

### \*3 Daisy chain

A daisy chain is formed by linking IC package lead terminals and PCBs together in a series. The resistance drop at a single lead terminal pin is slight, and so when evaluating soldered connections, multiple pins are connected and the changes in resistance of these together are measured to find evidence of solder cracking.

### \*4 2012 type

This term is used to express the size of surface-mounted parts such as resistors and condensers. The 2012 size is 2.0 mm (L) × 1.25 mm (W). Other sizes are 3216 (3.2 mm × 1.6 mm), 1608 (1.6 mm × 0.8 mm), and 1005 (1.0 mm × 0.5 mm).

### \*5 SOP (Small Outline Package)

The SOP is a type of IC package in which the leads come out from 2 sides of the package and form a gull-wing type (L-shaped) package.

### \*6 Void

Air bubbles inside the soldered joints are referred to as voids.

### \*7 Flow soldering

In flow soldering, melted solder is flowed onto the PCB to form a soldered joint. The dip method and the injection method are representative types of the molten solder bath.

### \*8 Land

This term refers to a conductor pattern used in attaching and soldering parts. Conductor patterns include such methods as pads for surface mounting and patterns surrounding parts installation holes.

### \*9 Solder fillet

The solder fillet is the form of solder build-up when soldering part leads and lands. It is used to determine whether the appearance of the soldering is acceptable.

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### [Bibliography]

- 1) National Center for Manufacturing Sciences, "Lead-Free Solder Project Final Report", NCMS Report 0401 Re96, 1997
- 2) Tadatomo Suga, "NEDO Project for R&D of Lead-free Solders toward Practical Solution and Standardization", The Journal of Reliability Center for electronic components of Japan, Vol.26, No.3, p.12-17, 1999
- 3) Tadatomo Suga, "Lead-free solder technology", The Nikkan Kogyo Shimbun, Ltd., 1999.
- 4) Yoshiharu Kariya and Masahisa Otuka, "Lead-free solder technology", Chapter 6, The Nikkan Kogyo Shimbun, Ltd., p.97-190, 1999.
- 5) Katsuaki Sukanuma, Koichi Niihara, Tatsumi Moritho and Yoshikazu Nakamura, "Properties of Sn-Bi Solders and Its Interface with Cu", The Journal of Japan Institute of Electronics Packaging, Vol.12-6, p.406-412, 1997
- 6) Tetsuya Nakatsuka, Hanae Shimokawa, Tasao Soga, Koji Serizawa, Asao Nishimura, Yoshiharu Inaba, Terumichi Nishino and Takeshi Terasaki, "Effect of Bi Content on the Reliability of Sn-Ag-Bi-Cu Lead-Free Soldered Joints", mate'99, p.353-358, 1999
- 7) Katsuaki Sukanuma, "Lead-free solder technology", Chapter 3, The Nikkan Kogyo Shimbun, Ltd., p.35-55, 1999.
- 8) Ikuo Mori, Mitsuharu Yamabe, Naoya Watanabe, Hisashi Ito and Koichiro Atsumi, "Effect of Bismuth Addition on Joint Reliability of Sn-Ag-Bi Solders", mate'99, p.359-364, 1999
- 9) Yasuo Yamagishi, "Lead-free solder technology", Chapter 7, The Nikkan Kogyo Shimbun, Ltd., p.165-173, 1999.
- 10) Sachio Yoshihara, Makoto Nakamura, Hirokazu Tanaka and Takashi Shirakashi, "In situ analysis of the ionic migration processes of lead-free solder using quartz crystal microbalance", MES'99, p.145-148, 1999
- 11) Hirokazu Tanaka, Makoto Nakamura, Fumitaka Ueta, Sachio Yoshihara and Takashi Shirakashi, "Factor Analysis on Ionic Migration Process of Lead-Free Solder Using QCM Method", The Journal of Japan Institute of Electronics Packaging, Vol.3, No.7, p.600-606, 2000
- 12) Katsuaki Sukanuma, "Developments in Lead Free Soldering", The Journal of Japan Insutitute of Electronics Packaging, Vol.12, No.2, p.83-89, 1997
- 13) Katsuaki Sukanuma, "Lift-off(Fillet-Lifting)", The Journal of Japan Institute of Electronics Packaging, Vol.3, No.5, p.445-449, 2000

# The occurrence of tracking in Printed Circuit Boards using organic insulating materials

Yuichi Aoki\* Hirokazu Tanaka\* Hiroko Katayanagi\* Shigeharu Yamamoto\*

*The current heightened level of concern with respect to environmental problems has brought about a trend toward eliminating fire-retardants such as halogen materials and antimony from printed circuit boards (PCBs) used in electronic equipment. As a result, we now face difficulties in product development concerning how to maintain fire retardant properties and how to deal with tracking<sup>\*1</sup>. Since the Japanese product liability law has gone into effect, there has been a heightened concern with safety. Accidents due to tracking can cause fires, and examples of such accidents are continually occurring. Various test standards exist for evaluation, but complex factors are involved, and countermeasures cannot be obtained for all factors. We have investigated the effects of the basic factors related to the occurrence of tracking, and we shall present the results of our investigation in this report.*

## 1. Introduction

We have in the past reported on a broad spectrum of physical phenomena, for which we have proposed a variety of test standards.<sup>1)-5)</sup> In this report on the occurrence of tracking in organic insulating materials, we shall deal with complex factors from contaminants such as salt, chemicals, dust and grime, and damp environments due to dew condensation and mist. However, we must point out that other effects exist as well from undefined factors such as surface conditions, the surrounding environment, and usage conditions. Test standards must be seen as only one aspect of materials evaluation.<sup>4)</sup>

On the other hand, a number of accidents caused by tracking have already been reported to date. Failure analysis is crucial to an investigation into the cause of these accidents and to a study of countermeasures. To that end, the authors of this report have performed failure analysis to uncover the causes behind the failure of electronic equipment.

In addition to performing such analyses, it is vital to clarify the manner in which the above-mentioned conditions affect tracking. To fulfill these aims for this report, we have performed testing on standard specimens to grasp the basic characteristics of tracking under each of these conditions with the hope of clarifying the underlying causes.

## 2. Example of failure

Photo 1 shows how tracking appears when occurring on a printed circuit. In Photo (a), we can see that tracking has turned the central section between the terminals darker than in Photo (b), taken before the occurrence of tracking. The repeated occurrence of tracking causes the blackened area to spread and become conductive, resulting in micro-discharge. Depending on installation conditions, the micro-discharge could lead to combustion, and the presence of extraneous factors such as electrolytic solutions with high electrical conductivity is thought to increase the danger of an accident due to further tracking.

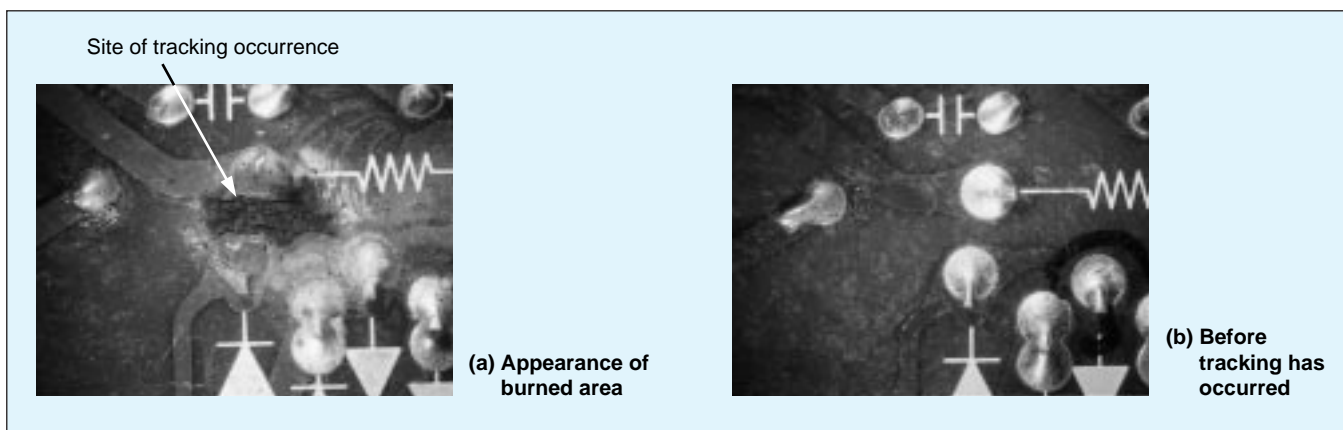


Photo 1 Example of failure

\*Environmental Test Technology Center

### 3. Mechanism and factors in the occurrence of tracking

Fig. 1 shows a model diagram for the mechanism of tracking occurrence. The direct cause of tracking is creeping micro-discharge.<sup>(2)</sup> This type of discharge stems from Joule heating caused by leakage current flowing in contaminated water, and dry patches appear as a result of the heating. Therefore, the concentration of the electrolytic solution (electrical conductivity) of the contaminated water and the effects of wetness have to be thoroughly investigated.

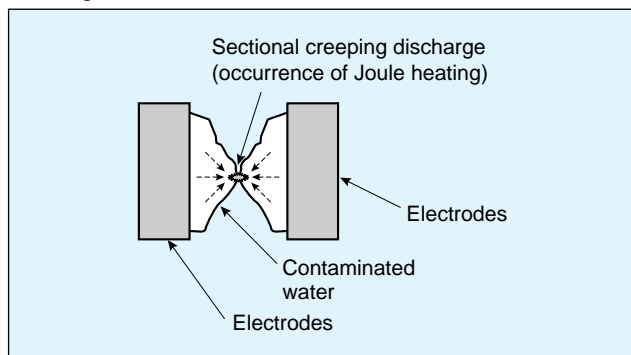


Fig. 1 Mechanism in the occurrence of tracking

### 4. Test methods

Fig. 2 shows a schematic diagram for these tests, and Table 1 presents test conditions. The test methods are based on IEC 60112 (“Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions”), focusing on evaluation tests mainly for electronic equipment. The test conditions use the local commercially-available power consisting of 50Hz current and low voltage. Test specimens consist of opposing electrode circuit patterns on PCBs. The space between electrodes was varied to check the correlation of occurrence at each distance. This approach yielded a detailed pattern for evaluation, and also since the electrode shape corresponds to the distance between electrodes, we used comb-shaped electrodes. A phenol resin with a high ratio of energy with which carbon is generated in integrated energy at pyrolysis ( $\Delta H_c/\Delta H$ ) was selected as the PCB material. For the electrolytic solution, we used the 0.1%  $\text{NH}_4\text{Cl}$  prescribed in the IEC tracking test method, and we studied the effects of using different concentrations of electrolytic solutions as well.

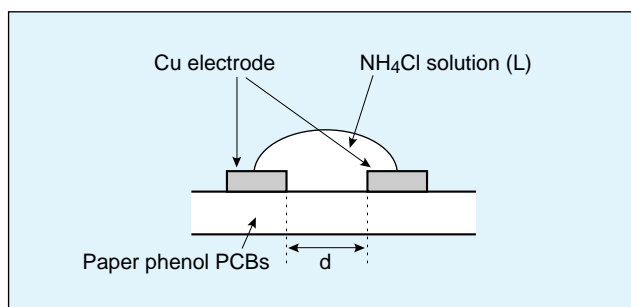


Fig. 2 Test Method

Table 1 Test conditions

Electrode gap	d = 0.165, 0.318, 0.635 mm
Electrolytic solution	$\text{NH}_4\text{Cl}$ solution 0.1, 0.5, 1.0, 2.0 weight % (0.1%: $395\Omega \cdot \text{cm}$ at $23^\circ\text{C}$ ) Capacity $L = 1 \mu\text{L}$
PCB material	Paper phenol (CTI:600V, Min.)
Electrode material	Cu
Surface processing	None
Application time	10 sec./1 drop
Tracking determination	Min. 1 Amp. leakage current

### 5. Test results and considerations

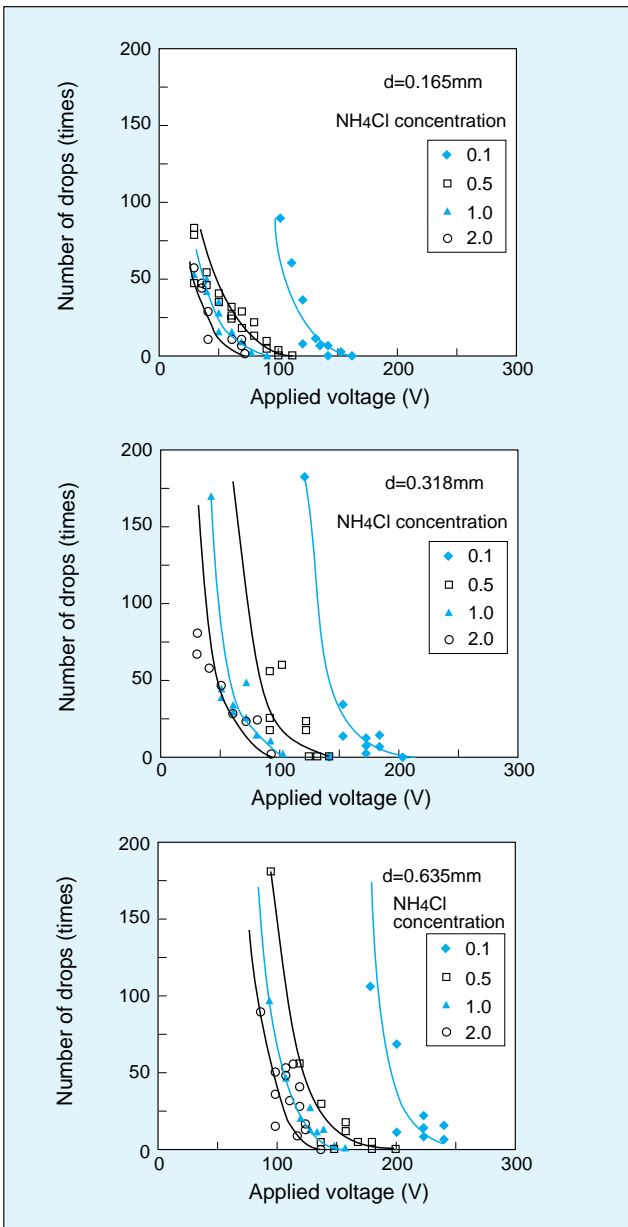
#### 5-1 The relationship between electrolytes and electrode spacing

Fig. 3 shows test results. A lack of reproducibility is often mentioned as a problem with tracking tests using the drip method. These tests also showed such evidence of a reproducibility problem, since the reduction in the number of drops that normally accompanies a rise in voltage was not seen, even when the voltage had risen locally. This phenomenon is thought to be caused by the rapid evaporation of the electrolytic solution between the electrodes, making the contaminants unavailable. Because of the dispersion of these measured values, we averaged values of repeated tests to confirm the cause of this dispersion. Tracking did not occur below 30 V in any of these tests, and a slight tendency toward ignition at around 40 V was confirmed.

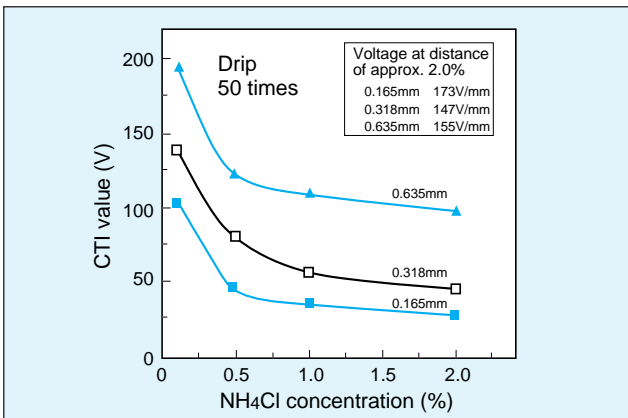
#### 5-2 Considerations regarding the electrode gap and the electrolytic solution concentration

The graphs in Fig. 3 investigate the relationship between the voltage when tracking occurred (CTI, Comparative Tracking Index) and the concentration of the electrolytic solution (electrical conductivity) after 50 drops. Fig. 4 shows the results of that investigation. At a concentration of around 0.1%, there was a large change in the CTI value due to a change in concentration. As a result of this pattern, the graphs converge as the concentration increases, and at above 1.0 to 2.0 percent, changes in concentration had little effect, obtaining a tendency for the CTI values to become almost uniform. This is thought to indicate uniformity of electrical discharge. When we look at the electrolytic strength (V/mm) as in the table annexed to Fig. 4, tracking occurs at roughly the same time at a concentration of 2.0 percent for electrode intervals from 147 to 173 V/mm. Also, as we can see in Fig. 5, the CTI value is roughly in direct proportion to the electrode gap at a concentration of 2.0 percent. In other words, in this region of convergence, we can see that electrical discharge depends on the electrolytic strength (V/mm) such as seen in the gas discharge phenomenon. However, even if the distance between electrodes is changed, if there is not an analogous change in the overall shape in the relative distance between the electrodes, we don't believe that the results obtained will be proportional to the changes in the

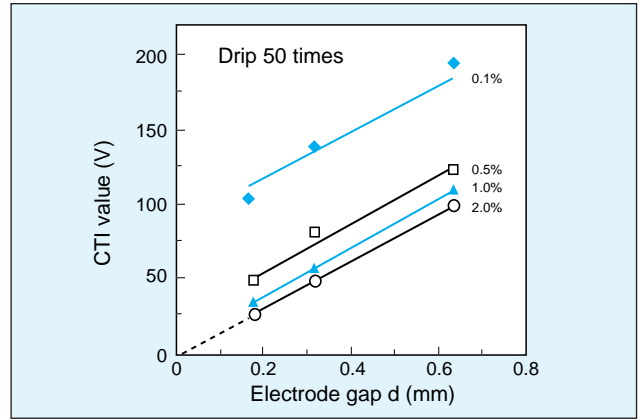
distance between the electrodes. As Fig. 6 shows, concurrent to low concentrations such as 0.1 percent, the differences in the electrode gap can be deemed to have a significant effect.



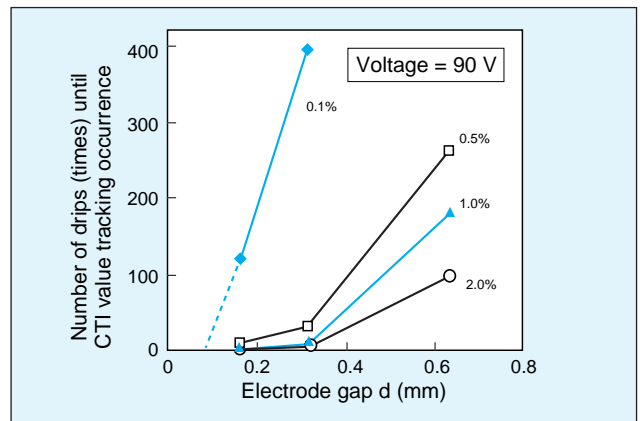
**Fig. 3 Tracking voltage features**



**Fig. 4 Electrolytic solution concentration – CTI characteristics**



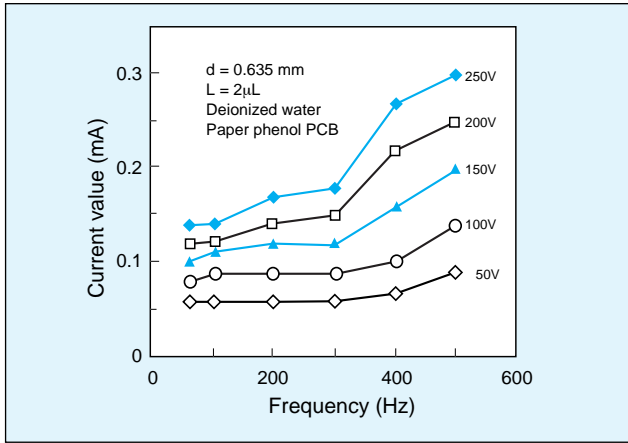
**Fig. 5 Electrode gap – CTI characteristics**



**Fig. 6 Relationship between electrode gap and number of drips until tracking occurs**

### 5-3 The relationship between frequency and current

The main cause of tracking is Joule heating resulting from leakage current, and AC/DC differences have been reported between the location of dry patches and discharge initiation<sup>3</sup>). Because of this, we investigated frequency characteristics as a parameter affecting current. Approximately the same test conditions were used as those in Table 1, the electrode gap was 0.635 mm, with a deionized water drip of 2 $\mu$ L on the PCB, and then we measured the relationship between voltage, frequency, and current. Fig. 7 shows the test results. As the frequency rose, the current began to rise as well, but that rise was shown to differ from the rising curve due to voltage. The cause of the increase in current is thought to be from such causes as the ion effects from the PCB resin. Since the characteristics differ with glass epoxy materials, there is thought to be a correlation with the PCB materials.



**Fig. 7 Frequency-Current characteristics**

### 5-4 The relationship between wetness and voltage

The problem of PCB wetness is closely connected to tracking characteristics. When tracking occurs as a result of phenomena such as mist and dew condensation, the initial water droplets exist independently, but as the wetness increases, bridging creates conductive pathways, and thus leading to tracking. The cause of changes in wetness, or the angle of contact, include various factors such as moisture absorption, materials, and the surrounding environment. Because of this, test materials were all subjected to identical washing and drying conditions. The method of measurement consisted of dripping deionized water of 2µL onto a 0.635 mm paper phenol pattern, and investigating changes in voltage and frequency parameters. Photo 2 shows the condition one minute and 30 seconds after the start of the test. No major changes were seen after that time.

Changes in wetness were not observed on copper electrodes, but were observed on paper phenol PCBs. Affects from voltage were observed at a minimum 150 V AC, and the angle of contact decreased as the voltage increased, and wetness expanded. However, no effects were observed that could be attributed to frequency. Once electrical discharge had begun, wetness immediately expanded, but this was attributed to the base becoming organic due to surface oxidation, and thus becoming hydrophilic. Two mechanisms were suggested for wetness: the reciprocal effects of the polar molecules of the PCB materials, and the penetration of water molecules.<sup>2)</sup> We can conjecture that applying voltage affects these mechanisms. Reports indicate that with the application of a minimum of 15 kV, the shape of the droplets becomes elliptical and are distorted horizontally in the direction in which the voltage is applied.<sup>2)</sup> As a result, we can assume that the higher the voltage used in electronic equipment, the greater the possibility of the occurrence of tracking due to wetness spreading.

	500Hz	300Hz	100Hz	60Hz	Changes in water droplet condition
250V					
200V		/			
150V					
100V		/			Initial condition

**Photo 2 Changes in wetness due to voltage – frequency**

## 6. Summary

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We used the drip method to perform tracking tests on comb-pattern electrodes on a paper phenol resin base. The following results were obtained for the factors of electrolytic solution concentration, electrolytic strength, frequency, and wetness.

- (1) For electrode gaps in the range of 0.165 to 0.635 mm, with a high concentration (1 to 2%) of electrolytic solution of  $\text{NH}_4\text{Cl}$ , the concentration dependence of the CTI values decreased, and the relationship between the electrode gap and the CTI value approached approximately direct proportion.
- (2) At low concentrations such as 0.1%  $\text{NH}_4\text{Cl}$  electrolytic solution, variances in the electrode gap have a greater affect on the occurrence of tracking.
- (3) Leakage current affects frequency, and the significance of that influence is connected to the level of voltage applied.
- (4) PCB wetness expands due to applied voltage, but is unaffected by frequency.

## 7. Future themes

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In the evaluation testing done for this report, we tried to uncover phenomenological aspects of tracking with undetermined factors indicated. As a result, we would like to take up such matters as physical interpretations for future themes.

## Terminology

### \*1 Tracking

The formation of electrically conductive pathways on the surface of solid insulation materials due to complex affects of electrical fields and surface contaminants containing electrolytic substances.

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### [Bibliography]

- 1) Japanese Standards Association, "JIS C 2134: Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions", Japanese Standards Association, 1996.
- 2) Noboru Yoshimura, Makoto Nishida, and Fumitoshi Noto, "Wetting and Discharge Inception on Organic Insulating Materials in Atmosphere of Fog", OYO BUTURI, Vol.47, No.6, p.538-546, 1978.
- 3) Boxue Du, Akio Suzuki and Shigeo Kobayashi, "Tracking Resistance of Organic Insulating Materials with Direct Voltage 2", DEL-96-7-14, The Institute of Electrical Engineers of Japan, p.63-72, 1996
- 4) IEC 60112, "Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions", 1979
- 5) UL 746A, "Comparative tracking index and comparative tracking performance level categories of electrical insulating materials", 1995

# Topics 1

## Network applications for environmental testing equipment

Katsumasa Suyama\*

### 1. Introduction

Network technology is evolving at an amazing pace. Fusing this modern network technology with environmental test equipment incorporating our smart-controlled instrumentation technology has enabled us at Tabai Espec not only to provide for the environmental test site, but also to offer the customer a comprehensive line-up of powerful environmental testing equipment incorporating new concepts of added value.

I would like to take this opportunity to introduce some of the applications that we have developed in this field.

### 2. Aims of E-PILOT21

We have devised a grand design for network technology to lead environmental testing into the 21st century. We call this concept E-PILOT21.

This concept is World wide and Time saving, and features the following three key phrases.

Easy Measurement: for simple test preparation and measurement!

Easy Report: for immediate test results!

Easy Maintenance: for time-saving, practical supervision!

Based on these development policies, we are meeting the challenge of providing applications suitable for the advanced information society represented by the internet. The functions that we build into our applications create happy customers.

### 3. Applications

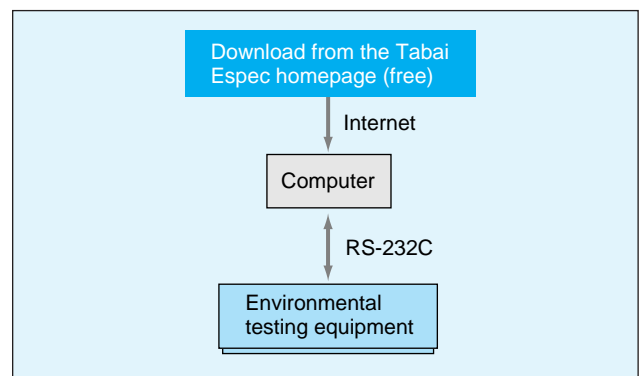
At this point, I would like to introduce some of our applications based on the E-PILOT21 concept.

#### 3-1 Software solutions for Espec environmental testing equipment

The “ERC-100 Series” software for Windows computers has advanced functions featuring ease of installation and ease of use.

#### ■ ERC-100S

ERC-100S is a software program that can control environmental testing equipment from a computer.

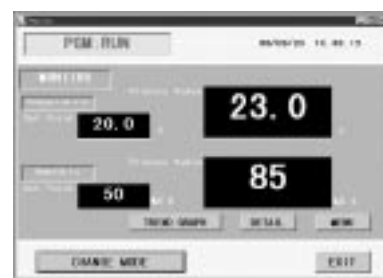


#### Freeware

This application is freeware that can be downloaded directly from our homepage and be used immediately when needed.

#### Remote device software

We have created remote device software that brings the monitor image of the instrumentation equipment closer to the operator so that the operator doesn't have to stand in front of the environmental testing equipment.



Monitor information screen



Trend graph screen

\*Technical Center

### Easy control and logging of data

The software can automatically record a test operation and save it to a universal CSV (comma separated value) file. This file can then be opened in spreadsheet software such as Excel for analysis and graphing. Reports can be made quickly and easily after a test has finished.



Log file creation screen



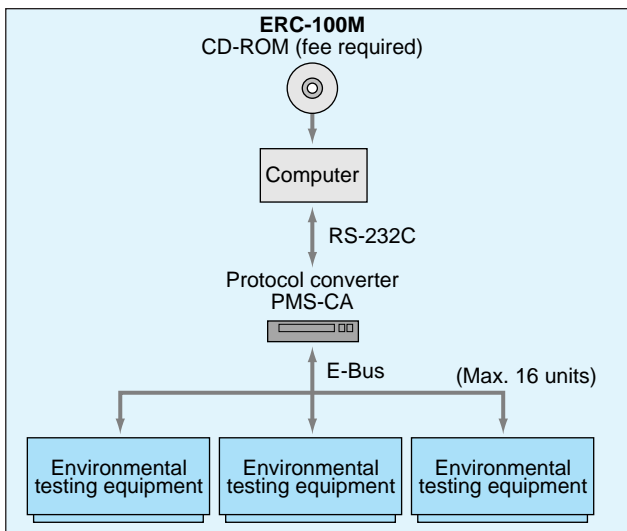
Log file setup screen

### Alarm pop-up function

Even when ERC-100S is running in the background under the Windows task bar, a pop-up window appears on screen when an alarm is generated.

### ■ ERC-100M

The software can provide centralized control of up to 16 units of environmental testing equipment.



### Unified control of operating profile

Even with environmental testing equipment that has different types of instrumentation, this software is capable of being operated with a single user interface. Unified control of the various operating profiles has been achieved.



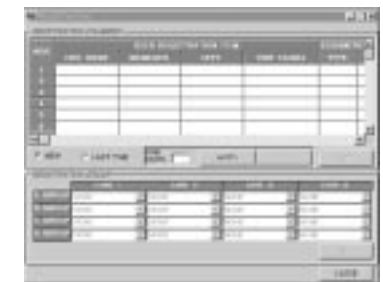
Program editing screen



Measured values recording screen

### Automatic function registration for connected test chambers

When chambers are connected to the network, the system automatically recognizes and registers functions such as the operating range of temperature and humidity.



Registration screen



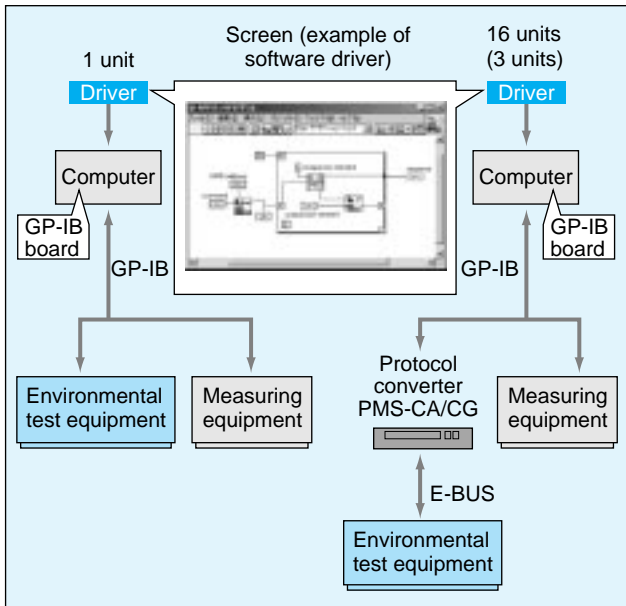
Group operating settings screen

For detailed information on the ERC-100 Series, please have a look at the Tabai Espec homepage. There are some restrictions on the PC environments and type of chambers applicable to ERC control, so please check that information.

### 3-2 Drivers for measurement software

With research test system conditions constructed by the customer, the various measuring instruments monitoring the specimens play a more important role than the environmental testing equipment.

Software drivers for LabVIEW (National Instruments, <http://www.ni.com/>) as a command conversion library for connecting environmental testing equipment and commercial measuring control software is available from the Tabai Espec homepage as freeware. Please download the proper driver (case 1, 2, or 3) for your application.



For detailed information on these software drivers, please see the Tabai Espec homepage. There are some restrictions on the PC environments and type of chambers applicable to ERC control, so please check that information.

### 4. Conclusion

We have introduced a few of the applications based on E-PILOT21, and in the future we will proceed with development of “next-generation environment test models” from the viewpoint of “presenting platforms (environmental test space) and contents (test and evaluation methods)”.

At Tabai Espec, we are developing new technology to meet the evolving expectations of our customers, so please keep an eye on our latest developments.

**Table 1 Driver overview**

	Overview	Input	Output
Case-1	Contains the bare minimum in command conversion library needed to connect LabVIEW (installed in PC) to an environmental test chamber via GP-IB communications.	Input the GP-IB (or chamber E-Bus) address and chamber command.	Chamber response is output in a format that can be edited in LabVIEW.
Case-2	In addition to the capabilities found in Case-1, Case-2 already contains chamber commands.	Input the GP-IB (or chamber E-Bus) address.	Chamber response is output in a format that can be edited in LabVIEW.
Case-3	Case-3 is a sample designed using Case-1 and 2 for monitoring. This can be used to help you build your own LabVIEW applications.	Input the GP-IB (or chamber E-Bus) address.	Chamber response is output in a format that can be edited in LabVIEW.

\* LabVIEW is a registered trademark of the National Instruments Corporation.  
 \* Windows is a registered trademark of the Microsoft Corporation.

**Feel free to access this homepage at any time.**  
 For detailed information on environmental testing network applications, please see our homepage (<http://www.espec.co.jp/us/e-pilot/index.html>).

# Topics 2

## Strategies for environmental protection

Hidenori Yoden\*

### 1. Introduction

In 1996, the Espec Group set the year 2000 as its target date for implementing the ISO-14001 international standard for environmental protection. At that time, we established a basic company-wide environmental policy for promoting environmental management.

We would like to take this opportunity to report on our “Environmental Management Report 2000” (written in Japanese) detailing the environmental management activities we have been engaged in through 1999.

### 2. Report publication

Our “Environmental Management Report” was first published in 1998, and contained a summary of all of our environmental management activity through 1997. We were able to publish approximately 20 thousand copies of that initial environmental management report for interested persons.

The current publication of this report, “Environmental Management Report 2000”, is our third issue, and summarizes our environmental management activity through 1999. We plan to continue publishing these reports annually.

### 3. Obtaining ISO-14001 certification

In 1996, the Espec Group initially planned to obtain ISO-14001 certification for its four main sites during the 1997 business year (lasting until the end of March 1998). Although a portion of the results fell somewhat behind schedule, in July 1998, the Tabai Kankyo Setsubi Co., Ltd. Daito site obtained certification, fulfilling our certification targets. The Tabai Kankyo Setsubi Co., Ltd. Daito site is manufacturing environmental testing rooms.

### 4. Substance flow

Our previous report covered this topic. Substance flow is a means of examining the amount of substances discharged by a corporation, thus revealing the extent of the impact that corporation has on the global environment. A substance flow report enables even persons unfamiliar with a corporation’s business activities to understand the corporate scale in relation to the environment.

On the input side of this equation, we purchased 561 tons of steel plate and stainless steel, which made up the major portion of the raw materials in our products. Unfortunately, we were unable to provide a total substance weight for commodities purchased as “parts”, such as electric parts and resin molds. In the future, we plan to oversee items such as substances and weights for parts as well.

Most of the energy required by our manufacturing activities is supplied in the form of electric power. Power consumption by the four sites that obtained ISO-14001 certification reached a combined total of 6.98 million kilowatt hours. Quantities of kerosene used for heating and gas used for air conditioning are also shown.

Freon is used as a coolant in the refrigeration circuits of our products. Currently, we have mostly completed our changeover to HFC freon, which boasts an ozone layer depletion coefficient of zero. This changeover was completed for our main products in autumn of 1999. Quantities purchased were 200 kg of HCFC, and 5,812 kg of HFC.

The Tabai Espec Service Corp., which performs service and maintenance for our products, travels to customer sites by automobile. The annual quantity of gasoline used for this activity totaled 251 kiloliters.

On the output side of this equation, we disposed of a total of 36 tons of waste. We have promoted such activities as recycling waste products at each site, separating waste thoroughly by type, getting rid of unnecessary packing and buffering materials, as well as retrieving waste materials generated in operations at customer sites.

The energy used in manufacturing generated a total of 845 tons of CO<sub>2</sub>. We set a goal of reducing our use of electric power by 20 percent (in manufacturing units). Electric power is our main source of energy, and we spared no effort in meeting this target in the year 2000.

The quantity of freon released into the atmosphere by manufacturing activities totaled 190 kg. This represents 3.2 percent of the quantity purchased. At the Espec Group, we have improved our air purge method used when sealing freon. (Air purging refers to purging the residual air from the hoses used when replenishing freon in the refrigeration circuits. It is impossible to purge this air without releasing some freon with it.) Our new method releases only one-tenth as much freon into the atmosphere as the old method. In addition, we have improved our

\*Environment Management Department

manufacturing processes by installing freon recovery devices to recover freon from refrigeration circuits requiring readjustment in those processes. We believe the effects of this improvement will become evident.

The Tabai Espec Service Corp. conducts freon recovery. This activity, (fee charged) includes recovering freon from products at customer sites when repairing refrigeration circuits, and also recovering freon from products that are being disposed of at the end of product life. This activity, which has obtained customer support, has achieved a 100 percent recovery rate, preventing 1,202 kg of freon from being released into the atmosphere.

## 5. Accomplishments

At the Espec Group, we set a 20-percent reduction target (in manufacturing units) for business use of electric power, and we spared no effort in meeting this target in the year 2000. Our accomplishments for 1999 show an 18-percent reduction compared to the power used in 1995.

We have established a company target of reducing waste products by 30 percent (in manufacturing units) by the year 2000. This represents a 64-percent absolute reduction in the amount of waste compared to 1995, and a 62-percent reduction in manufacturing units.

By the end of 1999, we had already managed to achieve our targets for the year 2000, approximately reaching our power consumption target and exceeding our waste product target. We are striving to maintain these

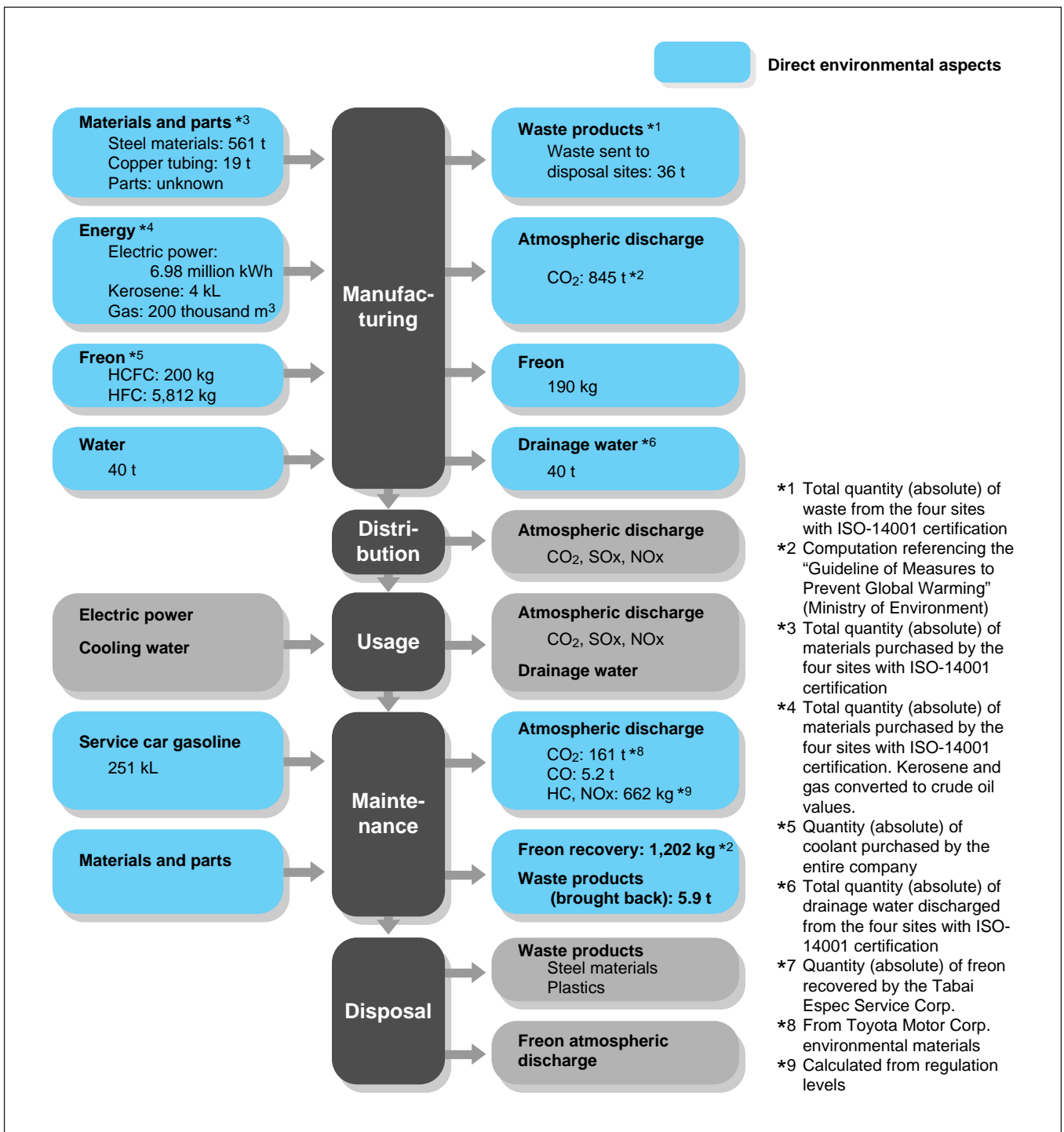
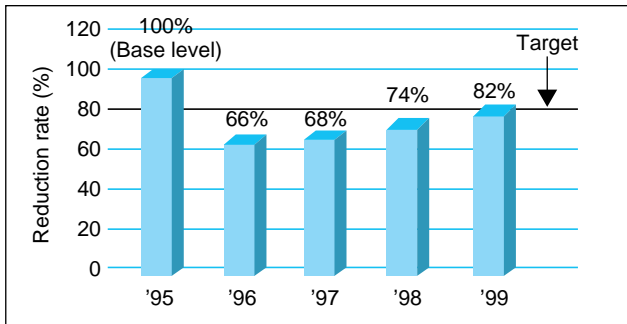
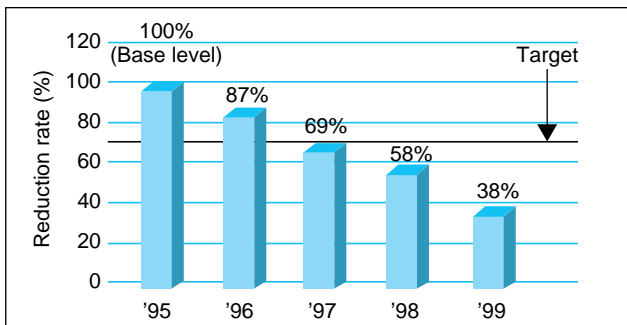


Fig. 1 Espec Group substance flow (1999)



**Fig. 2 Power consumption rate**  
(1995 base level manufacturing units)



**Fig. 3 Waste product reduction rate**  
(1995 base level manufacturing units)

reductions for the remaining year, and confirm this achievement.

## 6. Other items

The report includes the following items.

- (1) List of persons with environmental qualifications  
This section lists employees in the Espec Group based in Japan who have environmental qualifications. This focus provides a clear indication of the environmental consciousness of our company.
- (2) Presentation of data about materials  
All of the business locations that have obtained ISO-14001 certification (except Tabai Espec Service Corp.) have established independent standards for managing waste water. This section presents the results of such waste water management.  
Of course these waste water management standards adhere to laws and regulations and other requirements, and when results do not conform to the independent management standards, the causes are rigorously investigated and corrective measures are taken.

The report also discusses costs related to environmental management. While environmental accounting is a current hot topic of society, the Espec Group has calculated the costs incurred by activities stemming from environmental preservation, such as equipment investment and product improvements. This issue presents total cost calculations performed in accordance with policies set by the Ministry of Environment.

## 7. In conclusion

This article has presented an overview of the main contents of the “Environmental Management Report 2000.” The report is one means of presenting information to everyone sharing an interest in our company’s environmental management activities and the environmental consequences. We will continue to strive to present clearly-written environmental reports covering a broad spectrum of topics.

The report was written in Japanese only, but we are studying the possibility of presenting English editions of future reports.

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JIS Z 9901-1998 Registration Number JSAQ 004



JAB Certificate Number R001

### ISO 9001/JIS Z 9901

Quality Management System Assessed and Registered

The Quality Management System of TABAI ESPEC CORP. has been assessed and registered based upon the International Standard ISO9001-1994 and JIS Z 9901-1998, by the Japanese Standards Association (JSA).

**Products or Services:** Development, Design, Production, Installation and Servicing of Environmental Test Chambers, Environmental Test Equipments, Environmental Equipments for Production and Semiconductor Test Equipments.

#### The associated company within the scope of registration:

- TABAI ESPEC SERVICE CORP.  
 23-12, Taimahigashimachi, Neyagawa-shi, Osaka 572-0072, JAPAN  
 Servicing and Installation of Environmental Test Equipment
- TABAI KANKYO SETSUBI CO., LTD.  
 5-45, Shindenkitamachi, Daito-shi, Osaka 574-0052, JAPAN  
 Designing, Production and Installation of Environmental Test Equipment



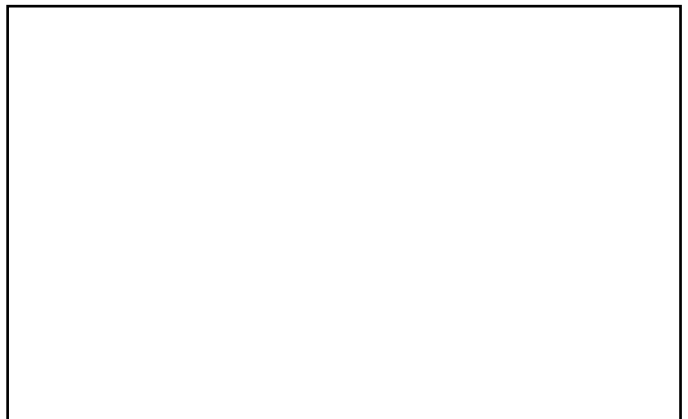
ISO 14001-1996

### ISO 14001 (JIS Q14001)

Environmental Management System Assessed and Registered

The Environmental Management System at TABAI ESPEC CORP. Fukuchiyama Plant, Utsunomiya Techno Complex and TABAI ESPEC SERVICE CORP. Head Office have been assessed and registered based upon the International Standard ISO 14001: 1996 and JIS Q14001: 1996, by Japan Audit and Certification Organization for Environment (JACO).

Name of organization	Approval Certificate No.	Subject to certification
Tabai Espec Corp., Fukuchiyama Plant	EC96J2046	The design and manufacture of Environmental test equipments and Semiconductor test equipments
TABAI ESPEC CORP. Utsunomiya Technocomplex	EC96J1081	The development, design and manufacture of Burn-in test systems and Evaluation systems
Tabai Espec Service Corporation Head Office	EC97J1050	The installation, inspection and maintenance for Environmental Test Equipments and Semiconductor Test Equipments
TABAI KANKYO SETSUBI CO., LTD. DAITO SITE	EC98J1033	The manufacture and installation of Environmental Test Equipments



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