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BSI Standards Publication

Electrochemical migration in printed wiring boards and assemblies — Mechanisms and testing

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National foreword

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RAPPORT TECHNIQUE

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inside

Electrochemical migration in printed wiring boards and assemblies – Mechanisms and testing

Migration électrochimique dans les cartes a circuits imprimés et assemblages – Mécanismes et essais

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COMMISSION

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ELECTROCHEMICAL MIGRATION IN PRINTED WIRING BOARDS AND ASSEMBLIES – MECHANISMS AND TESTING

FOREWORD

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IEC/TR 62866, which is a technical report, has been prepared by IEC technical committee 91: Electronics assembly technology.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
91/1102/DTR	91/1128/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Electronic products including components nowadays are designed to satisfy the demands for miniaturization, high functionality and environmentally friendly products. Various types of degradation occur in the electronic products used in the field. Appropriate measures are required to mitigate such degradation from the standpoint of reliability assurance. A study has been carried out to develop the understanding of the phenomenon and has proposed test methods for electrochemical migration with the purpose of suppressing the migration in products used in the field.

This Technical Report is related to electrochemical migration including conductive anodic filament (CAF). Specifically, it explains:

- the preliminary test: the steady state temperature humidity test, the temperature humidity cycle test, the unsaturated pressurized vapor test, the saturated pressurized vapor pressure test, the dew condensation cycle test and the water drop test;
- the insulation resistance measurement method: manual measurement, automatic measurement, a dielectric characteristics method, and an AC impedance method. Moreover, the difference between the measurement while the specimen is kept in the testing environment and not taken out of the chamber for measurement, and the measurement of the resistance of a specimen while it is taken out of the test chamber, and the merit of an automatic measurement are also described;
- the equipment used for analysis, the observation method of a failure part, and examples which are used for analysis.

This Technical Report generates a number of benefits for the user:

Usefulness	the user can examine the electrochemical migration test in a short time, and can use it as an indicator of exact analysis.
Test method selection	since for the user the test method which responds to the operating condition of the equipment or the purpose is clearly demonstrated, comparison of test condition becomes easy. Compared to the measurement resistance of a specimen while it is taken out of the test chamber after the test chamber is return to the standard atmosphere condition, the measurement in the test chamber by automatic measurement does not experience the environmental change of a specimen at the time of measurement, and since continuous measurement can be carried out, the resistance change and failure time can be grasped correctly.
Avoidance of trouble	by observing the notice on the test, the user can avoid a trouble and carry out test and analysis efficiently.

ELECTROCHEMICAL MIGRATION IN PRINTED WIRING BOARDS AND ASSEMBLIES – MECHANISMS AND TESTING

1 Scope

This Technical Report describes the history of the degradation of printed wiring boards caused by electrochemical migration, the measurement method, observation of the failure and remarks to testing in detail.

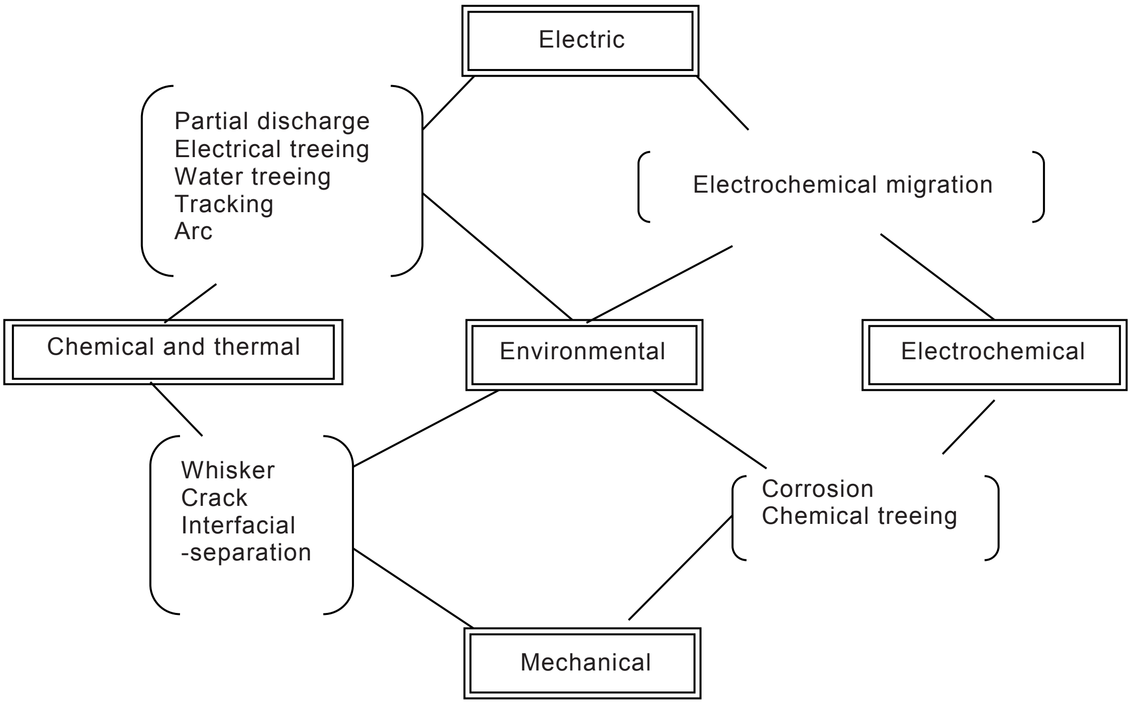
2 Electrochemical migration

NOTE Electrochemical migration is sometimes called ion migration. In this technical report electrochemical migration/ion migration will be referred to as migration.

2.1 Operation failure of electronic and electric equipment

It is known that failures caused by various degradation phenomena occur in electric and electronic products while they are used in the field. Causes of such failures are classified in Figure 1. The causes may be classified into: electric, thermal, mechanical and electrochemical origins. They are entwined with each other. The environment in which equipment is used also affects the generation of failures.

Growth of an electrically conducting filament caused by migration will short-circuit two conductors when a bias voltage is applied between them and will lead to a malfunctioning in the equipment.



IEC 1272/14

Figure 1 – Main causes of insulation degradation in electronic equipment

2.2 Name change of migration causing insulation degradation and nature of the degradation

2.2.1 History of naming with migration causing insulation degradation

Migration causing insulation failure had been called “ion migration” in Japan. A change of the definition of the phenomenon resulted in a change of name to “electrochemical migration”, but the name of “ion migration” is sometimes still used. The following description is the history of the change of name.

The first report on insulation failure was made in 1955, where the failure caused by the migration of silver atoms was reported and the phenomenon was called “silver migration”. It was also found that other metal atoms, including Pb and Cu, caused similar insulation failures, and so the phenomenon was called “metal migration”. The term “electromigration” was used as a general term for the phenomenon, and has been used for a long time in the IPC test method, IPC-TM-650:1987, 2.6.14A.

It was found since the latter half of the 1960s that interconnection failures in semiconductor devices were serious problems as the current flowing through a conductor significantly increased. This phenomenon was also called “electromigration”. The opening of a conductor was caused by the movement of metal atoms due to an increased current density, which produced dense and sparse layers within the conductor and resulted in a break of the conductor.

IPC changed the name of the phenomenon to “electrochemical migration” in its technical report IPC-TR-467A, and developed a new test method, IPC-TM-650:2000, 2.6.14C, which ISO adopted as ISO 9455-17. IEC 60194 which provides the terms and definitions for printed board design, manufacture and assembly, still uses the term “electromigration”. However, the name should be changed in the near future.

NOTE IPC-9201A uses and defines both electromigration (EMg) and electrochemical migration (ECMg).

References: 1) KOHMAN G. T., et al. *Silver migration in electrical insulation*, BSTJ 34 299, 1955
2) POURBAIX, M., *Atlas d’Equilibres Electrochimiques*, Gauthier-Villars et Cie ed., 1963

2.2.2 Process of degradation by migration

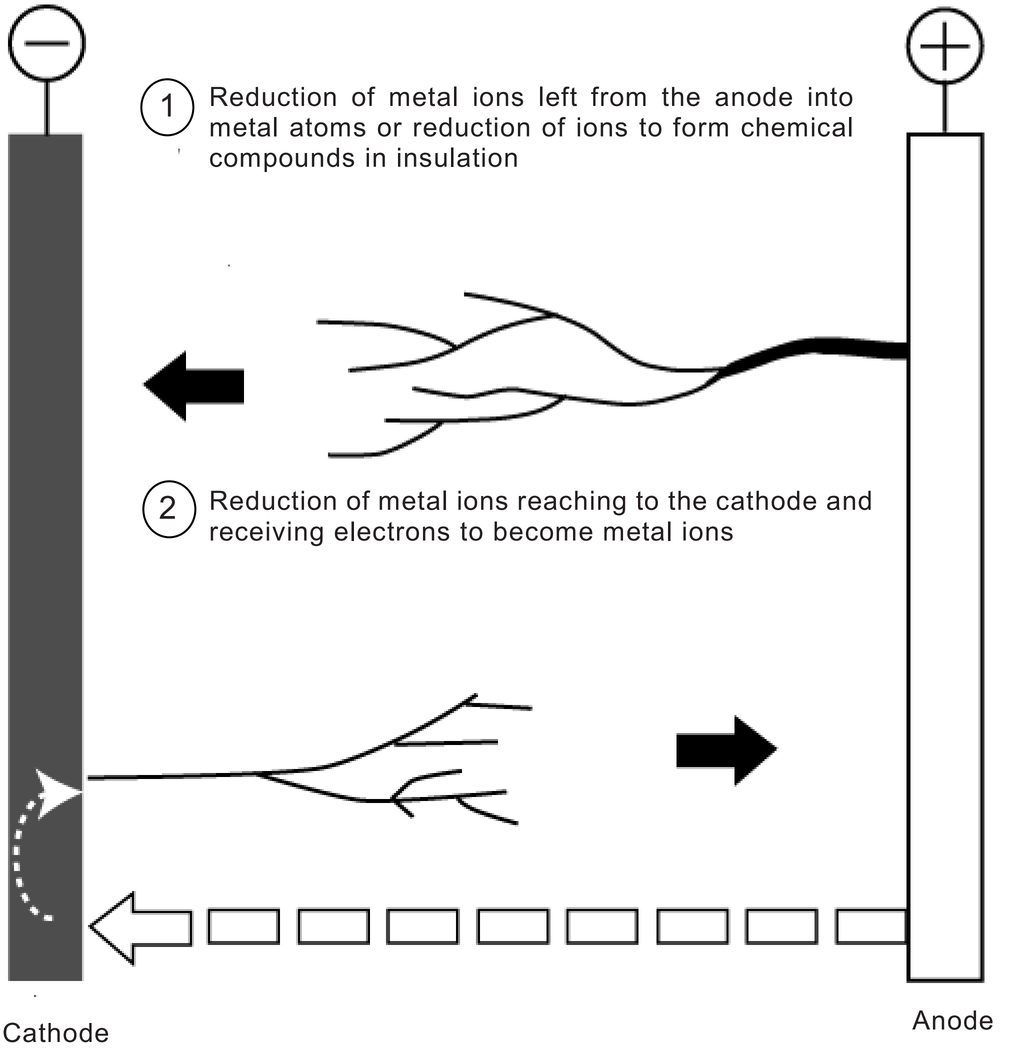
Good insulation between electrodes may be maintained in the application of DC voltage between electrodes on a printed wiring board of electronic equipment, as long as the electrodes are isolated by an insulating material of a high resistivity. If the insulating material absorbs moisture and the insulation resistance decreases, residual ionic contaminants in the insulating material or ions in the absorbed moisture will become active and metal atoms in the material will be ionized. Metal ions dissolve from the metal electrodes, either from an anode or a cathode, into the moistened electrolyte. Ions are transferred through the electrolyte by the electric field force. Metal ions (migration) move to an electrode and then educe in the form of dendrite. The dendrite bridges the neighbouring conductor electrode. The generation of (electrochemical) migration is described in 2.3.

2.3 Generation patterns of migration

Migration begins in the anode by dissolving as metal ions by an electrochemical reaction. There are two cases of this phenomenon as shown in Figure 2. In the first case, the reduction of ions into metal atoms or chemical compound molecules occurs somewhere in between the electrodes. In the second case, the reduction of metal ions occurs when the ions reach the cathode.

The first case is observed when the insulating material still maintains a high resistance to the order of 10^8 Ω or higher. The second case is often observed in HAST (highly accelerated temperature and humidity stress test), where the insulation resistance is reduced by the presence of dew, solder resist or cover layer on the insulation surface.

The difference in these two cases of migration seems due to the difference in the degree of easiness of movement of the metal ions. The second type of migration becomes dominant when the apparent resistance decrease exists and the metal ions can move more easily than in the first case, while the first case is dominant when metal ions resolve from the anode but cannot move easily in the insulation. The change of one mechanism to the other in the migration is not an independent phenomenon but is simply due to the difference in insulation resistivity of the electrolyte material between electrodes.



IEC 1273/14

Figure 2 – Generation patterns of migration

3 Test conditions and specimens

3.1 Typical test methods

the main test method for migration is shown in Table 1.

Table 1 – Standards for migration tests

<table>
<tr><th>Items</th><th colspan="2">Humidifying conditions</th><th colspan="3">Duration and bias</th><th>Document no.</th></tr>
<tr><td rowspan="3">Steady state Temperature/ humidity test</td><td colspan="2">40 °C ± 2 °C
93 % ± 3 %RH</td><td colspan="3">168^{+24}_{0} h
500 h ± 48 h
1 000 h ± 96 h</td><td>IEC 60068-2-78</td></tr>
<tr><td colspan="2">60 °C ± 2 °C
93^{+2}_{-3} %RH</td><td colspan="3">168^{+24}_{0} h, 500 h ± 48 h
1 000 h ± 96 h</td><td>IEC 60068-2-78</td></tr>
<tr><td colspan="2">85 °C ± 2 °C
85 % ± 3 %RH</td><td colspan="3">168^{+24}_{0} h, 500 h ± 48 h
1 000 h ± 96 h</td><td>IEC 60068-2-67</td></tr>
<tr><td>Temperature/ humidity cycle test</td><td colspan="2">Relative humidity: 90 % to 98 %
80 % in rising and falling period
1) Exposure to humidity followed by exposure to cold.
2) Exposure to humidity not followed by exposure to cold</td><td colspan="3">As agreed between user and supplier
About 1 000 h
DC voltage of 30 V to 50 V is usually specified</td><td>IEC 60068-2-38</td></tr>
<tr><td rowspan="2">Unsaturated pressurized vapour test</td><td colspan="2">110 °C ± 2 °C, 85 % ± 5 %RH
120 °C ± 2 °C, 85 % ± 5 %RH
130 °C ± 2 °C, 85 % ± 5 %RH</td><td colspan="3">96/192/408 $^{+2}_{0}$ h
48/96/192 $^{+2}_{0}$ h
24/48/96 $+^{+2}_{0}$ h</td><td>IEC 60068-2-66</td></tr>
<tr><td colspan="2">130 °C ± 2 °C 85 % ± 5 %RH</td><td colspan="3">96 h</td><td>JESD22-A110-B</td></tr>
<tr><td rowspan="2">Saturated pressurized vapour test</td><td colspan="2">121 °C, 205kPa (100 %RH)</td><td colspan="3">2 h, maximum 8 h
No voltage applied</td><td>JESD22-A102-C</td></tr>
<tr><td colspan="2">Pre-treatment (205kPa), 30 min
Then 260 °C solder immersion</td><td colspan="3"></td><td>IPC-TM-650:1994, 2.3.16.1C</td></tr>
<tr><td rowspan="5"></td><td rowspan="2">Condition</td><td colspan="4">Zone</td><td rowspan="5">JPCA ET 09</td></tr>
<tr><td>t_1</td><td>t_2</td><td>t_3</td><td>t_4</td></tr>
<tr><td>1</td><td>5 °C/ 60 %RH</td><td>≤ 20 s</td><td>25 °C/ 90 %RH, 20 min</td><td>≤ 15 min</td></tr>
<tr><td>2</td><td>0 °C, 25 min</td><td>≤ 20 s</td><td>30 °C/ 90 %RH, 20 min</td><td>≤ 15 min</td></tr>
<tr><td>3</td><td>–5 °C, 30 min</td><td>≤ 20 s</td><td>35 °C/ 90 %RH, 20 min</td><td>≤ 15 min</td></tr>
</table>

3.2 Specimens in migration tests

3.2.1 Design of test specimens

Design of specimens for migration evaluation depends on the region of a circuit board to evaluate migration. A conductive pattern for test should be selected according to the Japan Electronics Packaging and Circuits Association's JPCA ET 01.

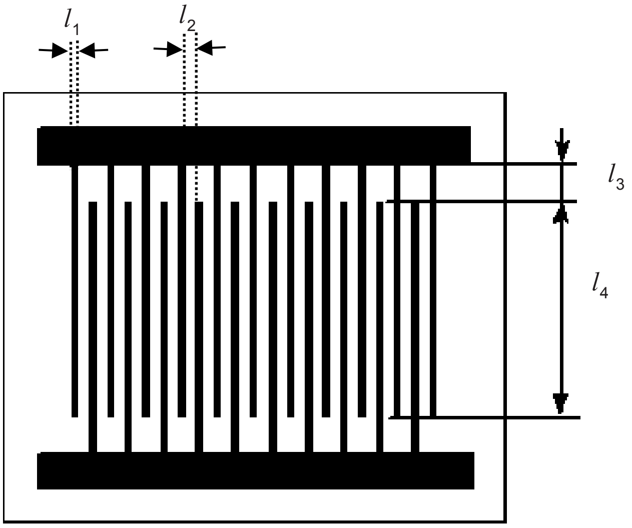
Only the patterns for surface insulation measurement are described here. The materials of the specimens are also defined in the previous edition of JPCA ET 01.

3.2.1.1 Pattern for evaluation of surface insulation resistance

Surface here means the board plane but does not mean the board surface itself. The pattern may be used for both top and bottom surface layers and also the inner layers of a board. The actual electrode size used in the products may also be used for test specimens. Two types of patterns are specified in this document.

1) JPCA ET 01
    a) Standard pattern

       The standard dimensions given in Figure 3 and Table 2 are specified. These dimensions are also compatible with those specified in IPC-SM-840. Fine patterns are not specified here. Standard patterns are widely used in the industry and the results of the measurement can be used for the comparison with the data in the practical field. The distance between two patterns should be more than 20 mm when more than one pattern is formed on the same board.



IEC 1274/14

Figure 3 – Basic comb pattern

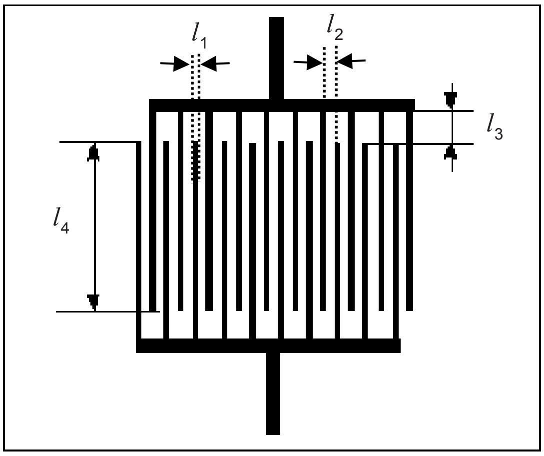
Table 2 – Standard comb type pattern (based on IPC-SM-840)

Dimensions in millimetres

Pattern	*A*	*B*	*C*
Conductor width (l_1)	0,165	0,318	0,635
Conductor gap (l_2)	0,165	0,318	0,635
Overlap (l_4)	15,75	15,75	15,75
Distance between conductor tip and base (l_3)	≥ 5,0	≥ 5,0	≥ 5,0

b) Fine pattern

There are many boards using fine patterns now. Fine patterns are specified in Figure 4 and Table 3 in this document. A finer pattern not stated in Table 3 such as of less than 50 μm may be defined in individual specifications.



IEC 1275/14

Figure 4 – Comb type fine pattern

Table 3 – Comb fine pattern (based on JPCA BU 01)

Pattern	*FA*	*FB*	*FC*
Conductor width (l_1)	50 μm	75 μm	100 μm
Conductor gap (l_2)	50 μm	75 μm	100 μm
Overlap (l_4)	10,0 mm	10,0 mm	10,0mm
Distance between conductor tip & base (l_3)	≥ 5,0 mm	≥ 5,0 mm	≥ 5,0 mm

The distance between conductor tip and comb type base pattern (l_3) should be more than 5,0 mm as results obtained may be affected if this distance is very short. We define only the overlap length of comb pattern conductors. The shape of the conductor tip should have some effect on the results but only the distance is defined here as it may be difficult to define the exact shape of the conductor tip and not practical.

2) Other test patterns

a) Test pattern used by the migration study group (ECM group)

The ECM Group uses the pattern shown in Figure 5.

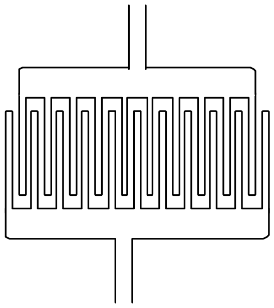
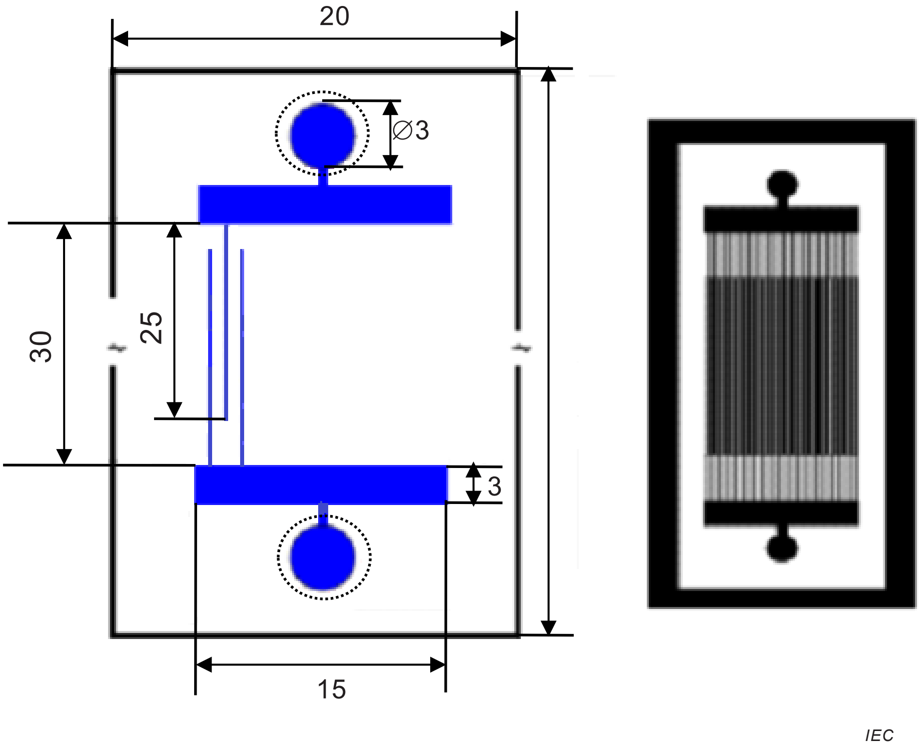


Figure 5 – ECM group comb type pattern (mm)

b) Test pattern used for flexible wiring board (see JPCA DG 02)

The test pattern specified in JPCA DG 02 is shown in Figure 6. The design guide for a flexible board includes the cover-lay and cover coat made of the same material. The number of conductor pairs is 75. The width and space (L/S) of conductors are chosen from the range of 60/60 μm to 100/100μm.

Dimension in millimetres



NOTE The circular areas surrounded by the dotted circles are openings of cover-lay and cover coat.

Figure 6 – Comb pattern for insulation resistance of flexible printed wiring board

3) Insulation resistance measurement pattern for an inner layer between inner layers

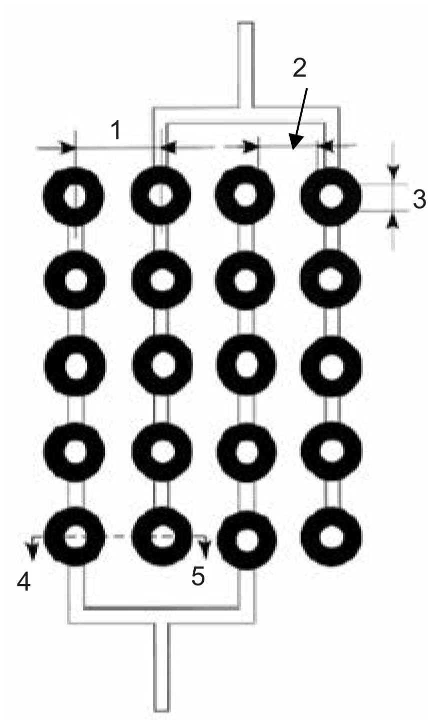
The evaluation pattern of the inner layer of a multi-layer board is also a comb pattern, the same pattern as that of the pattern for the evaluation of the surface layer. The same patterns are formed on two adjacent layers. One of the layers may be the board surface layer.

4) Insulation resistance measurement pattern between through-holes

a) JPCA ET 01

The evaluation of insulation between through-holes or via-holes is made using the pattern of two rows of through-holes or via-holes facing each other as illustrated in Figure 7. Details of Figure 7 are shown in Figure 8. The dimensions of the holes are given in Table 4. The holes are electrically connected. The figures show the case of through-holes. The diameter of holes is kept constant. The number of holes on a line is no less than five. Care should be taken that ion migration between potential feeding conductors (usually on the surface layer) should not occur.

The properties of copper-clad laminate (CCL) have directional dependence (vertical, horizontal and diagonal to glass cloth fibre direction). Test results may depend on the arrangement of holes and direction of the board used. It is advised to evaluate the board using specimens with different directions of holes.

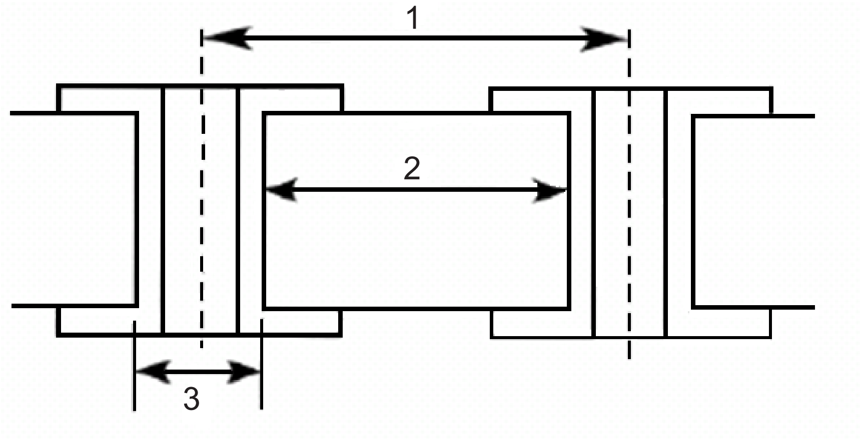


IEC 1278/14

Key

1	Hole pitch (p)
2	Wall to wall distance (s)
3	Hole diameter (d)
4 and 5	Cross section

Figure 7 – Insulation evaluation pattern for through-holes and via holes



IEC 1279/14

Key

1 Hole pitch (p)

2 Wall to wall distance (s)

3 Hole diameter (d)

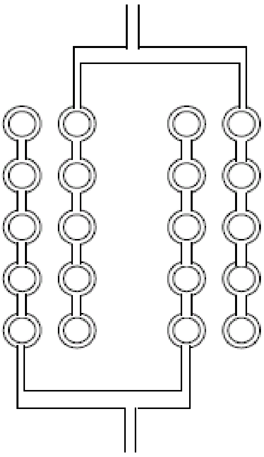
Figure 8 – Details of the insulation evaluation pattern of Figure 7 (cross section of 4 and 5)

Table 4 – Dimension of insulation evaluation pattern for through-holes

Hole diameter (d) (μm)	300					
Wall to wall distance (s) (μm)	150	200	250	300	350	400
Hole pitch (p) (μm)	450	500	550	600	650	700
Pattern arrangement	n holes × 4 rows (n ≥ 5)					

b) ECM group test pattern

The migration study group used the test pattern shown in Figure 9 for migration and CAF tests. Hole diameter and hole separation are specified for each test.



IEC 1280/14

Figure 9 – Test pattern of the migration study group

It is necessary to design a test pattern for the evaluation of insulation resistance between holes, inner layers for power supply and/or the ground plane of a board by varying the insulation distance. Due to the change of the insulation distance by the position shift during manufacturing, it is necessary to design the test pattern in such a way as to change the hole diameter and the diameter of the inner layer clearance to evaluate a variation in the insulation resistance. It is desirable to prepare two sets of test patterns, and perform the tests by setting the inner layer pattern as the positive electrode and the hole as the negative electrode for one set of tests and then reverse the polarity of the electrode for another set of tests.

3.2.2 Specifications and selection of specimen materials

1) Copper clad laminate (CCL)

There are two types of CCL, one for regular rigid printed wiring boards and the other for flexible wiring boards. CCL for rigid boards uses glass cloth as the base material, laminate with resin impregnated prepreg and copper foils. Products may be classified by the materials used as paper-phenol laminate, glass-epoxy laminate, and glass-polyimide laminate, or by grade specifications such as FR-4, GPY, and CEM-3. Flexible boards are laminates of resin film and copper foil, and may be classified as polyimide laminates and polyester laminates. Polyimide laminates are further divided into adhesive laminated boards and non-adhesive laminated boards.

The appropriate copper foil should be selected according to the purpose of the test. Highly migration resistive copper laminate should be used especially when evaluating the migration resistant materials and the precise characteristics of the boards. Migration resistivity varies significantly with the selection of the resin used. It is reported that glass-polyimide laminate is about ten times CAF resistive compared to glass-epoxy laminate of FR-4 grade. The migration characteristics of FR-4 grade glass-epoxy laminate vary significantly with the composition of resin, the types of glass cloth or the amount of resin used. Migration in flexible copper foil laminate boards significantly varies if adhesive is used. Polyimide laminates not using adhesive have significantly better migration resistivity compared to those using adhesives.

2) Copper foil

There are two types of copper foil according to manufacturing methods. One is electrodeposited copper foil and the other is wrought foil. Electrodeposited copper foil is used in most rigid boards and both wrought and electrodeposited copper foils are used in flexible boards depending on the board property requirements. The copper foil for evaluation should be selected for foils of proper type, thickness, surface roughness, and surface treatment. The thickness of the copper foil used in an inner layer may affect the lamination property of the inner conductor pattern and migration. Surface roughness of the copper foil used to form the comb pattern can affect the adhesiveness of copper foil and thus electrode formation. If the surface roughness is very large, the rough surface of the copper foil may not be sufficiently etched in the electrode formation and residue copper may remain in the gap between the copper electrodes. The copper foil with a rough surface may also touch the glass-cloth of laminated boards. These may become the factor to cause migration. On the other hand, a very smooth surface reduces the adhesiveness of copper foil and may cause peeling off during the test.

3) Solder resist

There are three types of solder resist: the development type, the thermosetting type, and the UV hardening type. Most of the solder resist used in production is the development type. This type of solder resist film is formed on a board by a screen print, a spray-coat, a curtain-coat, or a film lamination, and then patterns are made by photo-lithography.

It is necessary to select the proper type of solder resist in the evaluation of the board. The selection depends on the purpose of the test and the dimensions of the electrodes. A well-established technique should be used to apply the solder resist. Insufficient hardening of the resist may result in corrosion of the electrode pattern and in the opening of a test circuit. In this case the degradation of the insulation resistance cannot be detected. Voids may be formed if bubbles are included in the solder resist. Bubbles will be made by the screen printing at the interface of the resist and underlying copper. Insulation deterioration is observed even for an electrode spacing of 250 μm due to deterioration caused by the voids. The printing condition and the holding time to leave a specimen in a chamber for hardening after printing should be optimized especially when a fine pattern is used for test specimens.

It is known that voids are observed even in the solder resist of the dry film type, but voids in this case do not significantly affect the degradation of the insulation resistance because the electrodes are well covered by a dry film. There may be a case, however, where the dry film type solder resist may have inferior adhesiveness compared to the liquid type resist. Corrosion may occur at the interface and the inner pressure generated by the precipitates may break the resist film and cause migration.

3.2.3 Remarks on the preparation of specimens

1) Surface pattern

   The migration test result may be affected by the surface treatment of the board (such as UV treatment and plasma treatment), the surface treatment of the conductor patterns (such as electroplating) and the presence or not of the formation condition of the solder resist. The board surface should be carefully cleaned before applying the solder resist. The formation and curing conditions of the resist should be carefully checked so as not to form voids and non-hardened regions. Pin holes and non-plated parts should not be formed on the electrode when the surface of the conductor pattern is electroplated.

   The flux residue may cause an insulation defect when a cable is soldered to the conductor. The soldered joint should be cleaned thoroughly. The soldering heat may also deteriorate a specimen so that soldering should be made in as short a time as possible.

2) Inner pattern

   As in the case of the surface pattern, the surface treatment of the board itself or the surface treatment of the conductor pattern (oxidation or reduction conditions) may affect the test results for the inner pattern. In the lamination process of the board, sufficient and thorough cleaning of the laminating layers should be made. The laminating condition should also be checked so as not to cause de-lamination.

3) Through-holes and via holes

   Hole formation conditions including drilling, desmear, or electroplating of the inner wall of a hole may affect the results of the migration test. Such conditions should also be carefully checked.

3.2.4 Storing of specimens

Dust and some foreign particles may deposit on the surface of specimens if the specimens are left in open air in a room. In the case of organic resin materials, the amount of absorbed water vapour increases as time goes by and the insulation characteristics of the specimens may deteriorate. Care should be taken when storing the specimens:

1) Specimens should be stored in plastic bags or in a desiccator to protect them from contamination. If left in an open air, the surface of specimens may be oxidized, sulfurized, or salified. A box should be available where humidity inside the box may be controlled or filled with inert gas.
2) The surface of a desk should be discharged before specimen handling to protect it from dust deposition.

3.2.5 Pretreatment of the specimen (baking and cleaning)

Dirtiness between conductor patterns (dust, dirt, etc.) or absorption of water are the causes that deteriorate the insulation resistance and they have to be carefully checked before the test. Pretreatment of the specimens before the test may reset the target section of the specimen when the evaluation is planned to check the effects of board fabrication. Pretreatment may be employed to apply environmental stresses (heat, humidity history, etc.) to the specimen. Pretreatment should be chosen in accordance to the purpose of the evaluation. Explanations are given in the following for various pretreatments used for tests in this document.

1) Necessity of pretreatment
   a) Cases where pretreatment is necessary:
      - Evaluation of the conductor pattern design when the surface condition is not of significance.

  - Comparison of the characteristics of the specimens which are made at different times, or of specimens stored for a long time so that the surface conditions may have been changed, e.g. surface contamination or water absorption.
  - Removal of the flux residue on the conductor surface.
  - Other.

b) Cases where pretreatment is not necessary:
  - Cleaning using alcohol or acetone may dissolve impurities of specimen containing organic substances.
  - Evaluation of the surface treatment process and materials.
  - Other.

2) Pretreatment

Table 5 gives the general pretreatment to printed wiring board.

Table 5 – Surface pretreatment to printed wiring board

Purpose	Standard	Process
Cleaning	ISO 9455-17	Pretreatment of copper patterns for flux test: 1) clean specimen with purified water using a soft brush for 30 s 2) spray rinse with purified water 3) clean specimen with isopropyl alcohol using a soft brush for 30 s 4) rinse with isopropyl alcohol 5) dry the specimen in a dryer for 3 h at 60 °C
Drying	IEC 60068-1	Specimens are kept under the following condition for 6 h for pre-drying, if needed, before the start of a series of measurements: 55 °C ± 2 °C, < 20 %RH, atmospheric pressure of 95 kPa to 106 kPa
	IEC 60068-2-2	Keep the specimen at 25 °C ± 5 °C, and 45 %RH to 75 %RH until the temperature of the specimen becomes stable at the temperature. Change the humidity to 95 % to 100 %RH within 1 h.
	EIAJ ED-4701/301	Heat treatment that is usually performed as the pretreatment for soldering (125 °C ± 5 °C/24 h)
Preconditioning	EIAJ ED-4701/301 JESD22-A113	Heat and humidity treatment considering the environmental effects to the assembly process for surface mounting device (SMD) packages

3.2.6 Care to be taken in handling specimens

Care should be taken in handling the specimens as surface contamination affects the results considerably.

1) Operators should use disposal masks and latex gloves.
2) Work should be made on a sheet of dust free paper.
3) Use chlorine free flux.
4) Cover the conductor pattern with the dust free paper used in clean room in soldering not to splash the flux to the specimen surface.

3.3 Number of specimens required in a test

3.3.1 Specifications given in JPCA ET 01

The number of specimens required depends on the purpose of a test, for example whether a test is for test products or for mass produced products. There are few references giving the numbers clearly for any specific purpose of a test. Table 6 gives a rough guidance to the number of specimens required for the purpose of a test.

Table 6 – Number of specimens (JPCA ET 01)

Purpose	**Basic concept**
Evaluation of test product	Discrete device: $n \geq 5$ $n \geq 10$ is recommended
Evaluation of mass product	Discrete device: $n \geq 10$

3.3.2 Number of specimens in a test

The number of specimens required at different production stages is specified in JPCA ET 01 as shown in Table 6. For the evaluation of products at a test production stage n may be 5 but $n \geq 10$ is recommended. The difference in number for the specific purpose of a test is not standardized in this technical report but given in Table 7 as reference.

Table 7 – Approximate number of specimens required depending on the purpose of the test

Purpose			Consideration
Difference in production stages	Evaluation of design and test production		Discrete component: $n \geq 5$ $n \geq 10$ is recommended
	Evaluation of mass produced products		Discrete component: $n \geq 10$
Difference in the purpose of a test	a	Initial failures	– It is very difficult to decide n theoretically. – It is the best method to change the specimen number from the conventionally accepted number so as to obtain a reasonable result.
	b	Random failures	
	c	Failure levels (λ, MTTF)	– It is possible to decide n statistically. – n may become very large unless an accelerated test is adopted.
	d	Life	– A similar consideration stands as in a and b. – Only for single component with a finite life time.

3.3.3 Number of specimens for the different evaluation purposes of a test

1) If the purpose is a, b, or d of Table 7:

- For a and b

  The method to determine the number n from the available data of generation of failed components from the standpoint of the detection of a failure lot at a reliability level of 90 %.

- For d

  The method to determine the number n in the process of approval of the averaged and difference of quality to confirm there is no difference in the quality of the component of the interest.

2) If the purpose is c of Table 7:

   There are several sampling methods to select n to study λ, the failure rate, and the MTTF (mean time to failure) by a relevant test.

- Case in which an exponential distribution is assumed
  - Single sampling by attribute — MIL-STD-690
  - Single sampling by attribute T/r (total operation time /failure rate)
  - Sequential sampling — MIL-HDBK-781A
- Case in which a Weibull distribution is assumed
  - Sampling by attribute — ANSI/ASQ Z1.4
  - Sampling by variable — ANSI/ASQ Z1.9

For details, refer to the above-mentioned standards or to the description of the statistical sampling method of the reliability test.

The number of $n \geq 30$ is required to obtain an objective confirmation of the life of a product. Some say $n \geq 20$ is necessary to obtain an acceleration factor in a Weibull analysis while there is a text requiring $n \geq 50$. The cost of a test is roughly proportional to the number of specimens but the quality and quantity of information attainable from a test are increased as the specimen numbers are increased. It is necessary to decide on a proper number of specimens in the evaluation analysis and an optimum number should be selected considering the cost, the testing time and a comparison of the results with the available data from tests made before. A minimum number of 10 seems necessary in any case.

4 Test methods

4.1 General

Each test is performed using individual standard test. In Clause 4 the summaries of the purpose, the test equipment and test method, and the items to be noted for each test related to ion migration are described.

4.2 Steady state temperature and humidity test and temperature-humidity cyclic test

4.2.1 Purpose and outline of the test

There are two types of tests in this category. One is for the test keeping a specimen in an environment of a specified temperature and humidity for a specified time. The other, which is called a cyclic test, is to expose a specimen in an environment where a change of temperature and humidity is 1 cycle a day. The steady state temperature and humidity test is suitable to check the insulation degradation caused by absorption of water vapour while the cyclic test is used for insulation degradation due to forced dew formation in an environment as shown in SOURCE: IEC 60068-2-30:2005, Figure 2b.

Figure 11. There is another type of temperature-humidity cycle as shown in SOURCE: IEC 60068-2-38:2009, Figure 2 and Figure 3.

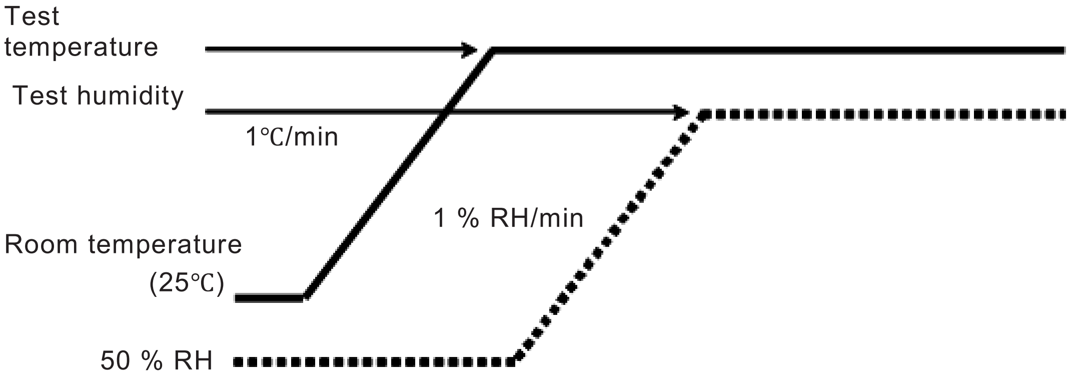
See 6.4 of IEC 60068-2-38:2009.

Figure 12 which includes a low (freezing) temperature to check the effects of both a freezing and high temperature environment on a specimen. The test including a dew formation effect may not be very stable as the dew formation on a specimen is not a stable phenomenon. A cyclic test for dew formation with more realistic environmental conditions is described in 4.5. Stabilization of a specimen in the testing environment, especially with a change of humidity condition is very important in these kinds of measurements. Recent improvements in materials inevitably require a very long time for such a temperature-humidity test.

4.2.2 Test profile

1) Steady state temperature-humidity profile

Care should be taken for dew formation on a specimen when the surface temperature of the specimen is lower than the dew point of the test chamber. Dew may be formed on the specimen surface in such a case. Dew may easily be formed when the heat capacity of a specimen is large and there is a difference between the chamber temperature and that of the specimen. Such a test is often made with a temperature profile shown in Figure 10 to avoid dew formation. The temperature is first raised followed by an increase of humidity to avoid dew formation on the surface of a specimen. It is recommended to change the temperature slowly with a rising rate of 1 °C/min and a humidity increase of less than 1 %RH/min.



IEC 1281/14

Figure 10 – Recommended profiles of increasing temperature and humidity

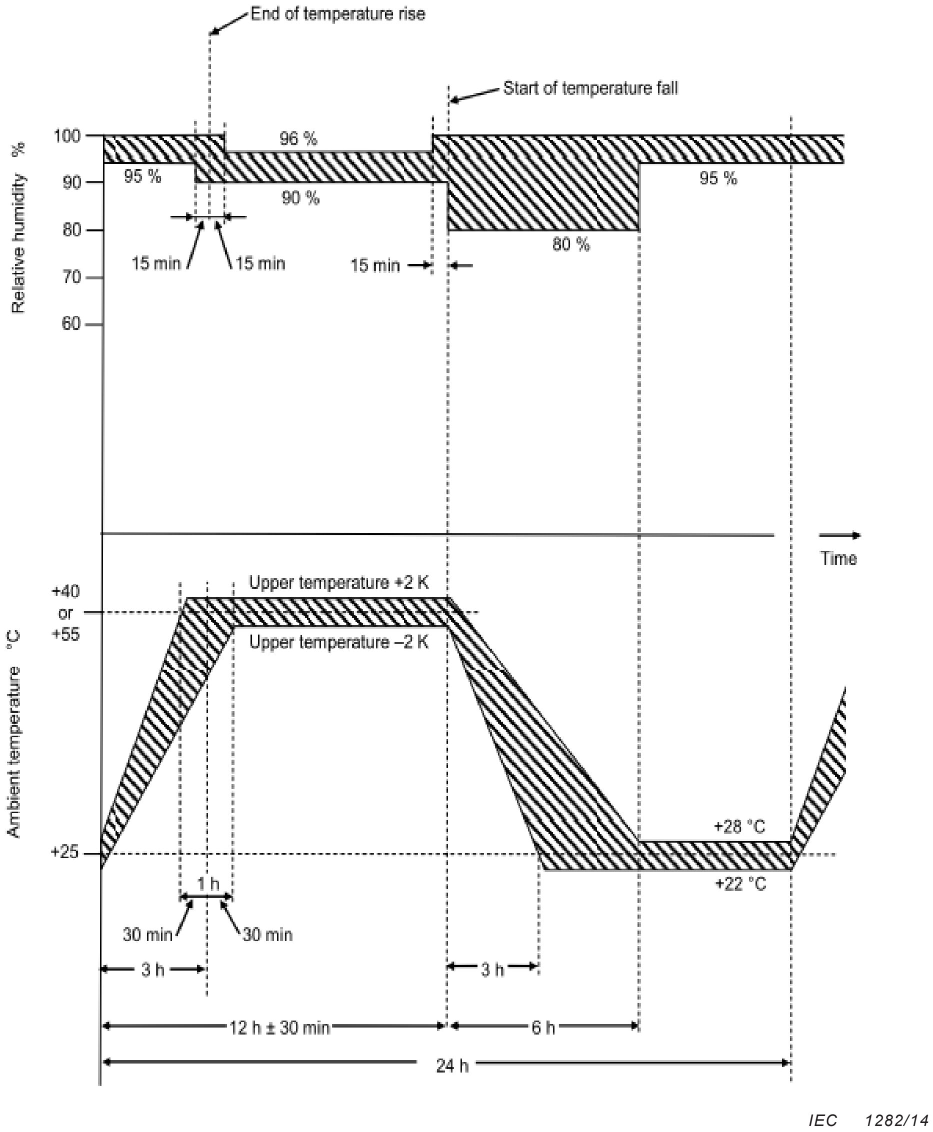
2) Temperature-humidity cyclic test profile

The purpose of the cyclic test is to check the effect of dew formation. Care taken to avoid dew formation as in the case of the steady state temperature and humidity test is not necessary. Follow up of the temperature of a specimen to the change of the chamber temperature is important in a temperature-humidity cyclic test. Control the temperature and humidity as specified in the individual specification. SOURCE: IEC 60068-2-30:2005, Figure 2b.

Figure 11 and SOURCE: IEC 60068-2-38:2009, Figure 2 and Figure 3.

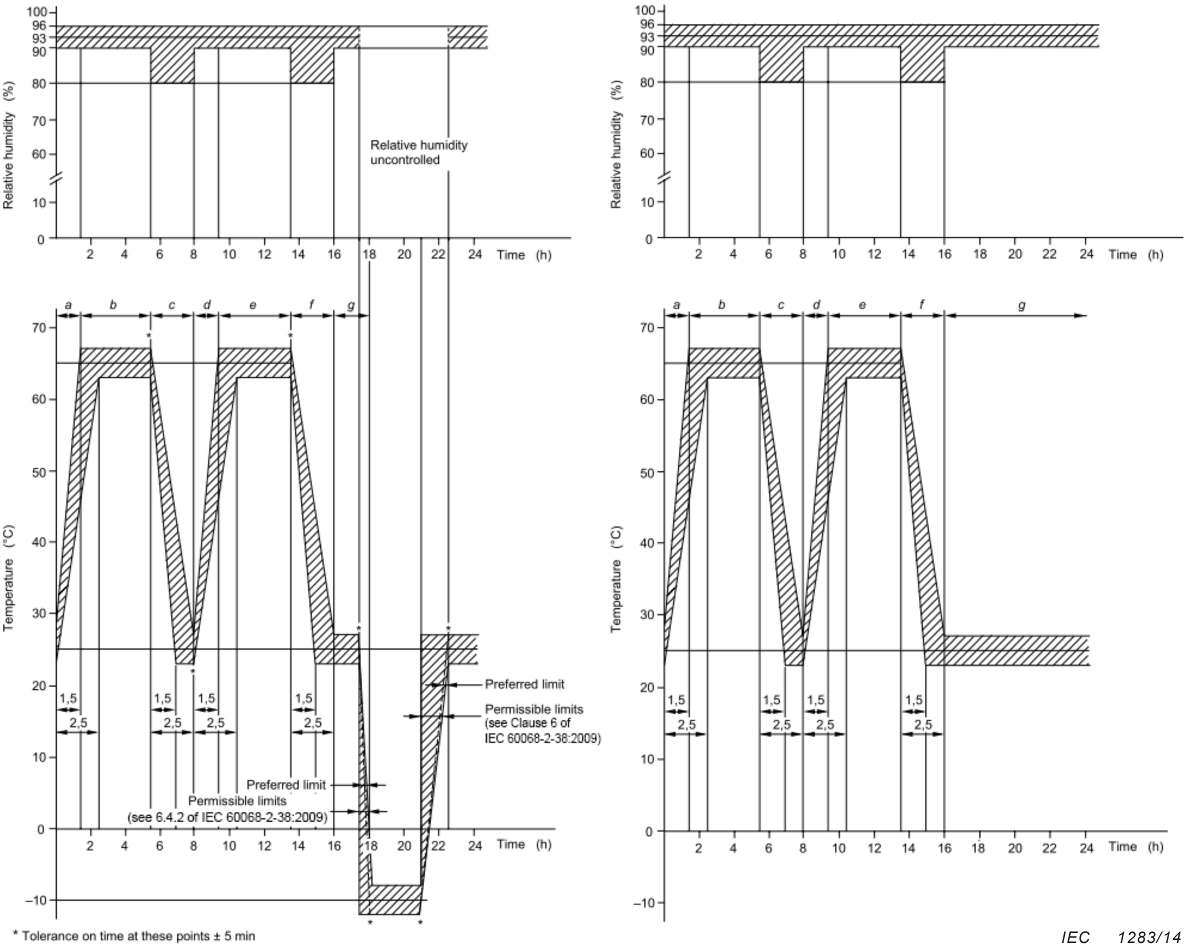
See 6.4 of IEC 60068-2-38:2009.

Figure 12 are the temperature profiles specified in IEC 60068-2-30 and IEC 60068-2-38, respectively.



SOURCE: IEC 60068-2-30:2005, Figure 2b.

Figure 11 – Humidity cyclic profile (12 h + 12 h)



* Tolerance on time at these points ± 5 min

IEC 1283/14

SOURCE: IEC 60068-2-38:2009, Figure 2 and Figure 3.

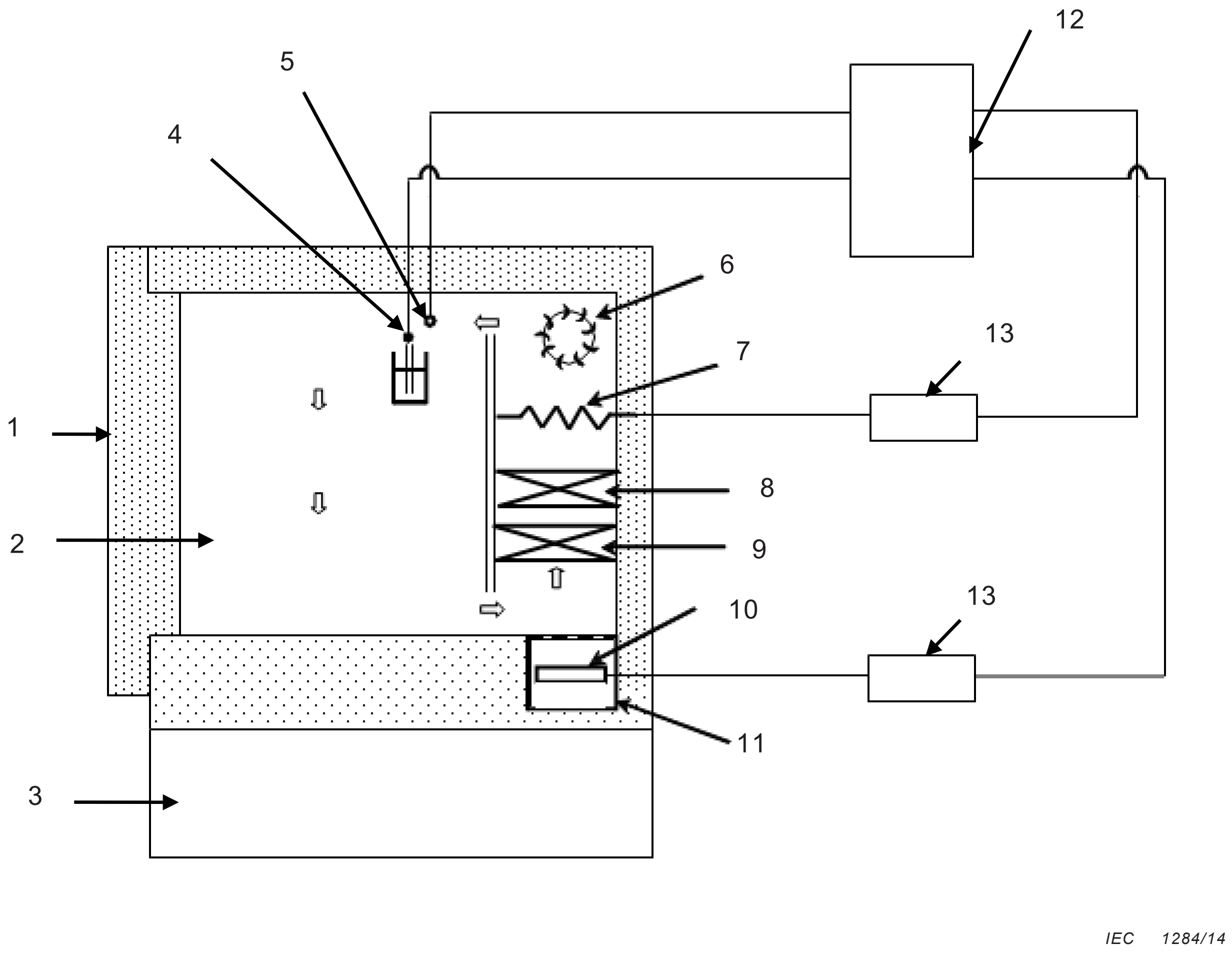
See 6.4 of IEC 60068-2-38:2009.

Figure 12 – Profiles of combined temperature-humidity cyclic test

4.2.3 Test equipment

1) Construction

A typical structure of the steady state temperature-humidity test equipment is illustrated in Figure 13 and main elements of the equipment are described.



Key

1	Door	2	Working space	3	Machinery room
4	Temperature sensor for humidity	5	Temperature sensor	6	Fan
7	Heater	8	Cooler	9	Dehumidifier
10	Heater for moisture	11	Humidifying water	12	Temperature and humidity controller
13	Solid state relay (SSR)				

Figure 13 – Structure of steady state temperature-humidity test equipment

a) Blower

The fan used in the equipment may be a sirocco fan, a propeller fan, or a line flow fan according to the required wind in the equipment. The material of the fan may be stainless steel, aluminium alloy, or carbon steel depending on the temperature in the chamber.

b) Heater

The heater may be either a strip-wire heater, a silicon rubber insulated heater or a sheath heater depending on the required heat and environment of the chamber. Some chambers use a Peltier heat element.

c) Cooler

A mechanical compressing refrigerator is commonly used. Some chambers use a Peltier heat element.

d) Dehumidifier

A dehumidifier is basically the same as a cooler. Some systems use a cooler for a dehumidifier.

e) Humidifier

There are several types of humidifiers. They are: a pan-type humidifier which has a pan with a heater, and water is poured in the pan and heated to generate water vapour; a humidifier unit which sends water vapour generated in a system installed outside of a chamber and sends the vapour into the chamber; an ultrasound humidifier which vapourizes fine water drops dropped on a ultrasound vibrator, or aerosol spray type humidifier. The pan-type humidifier is widely used because of its simple structure requiring a small space and also its low cost.

2) Temperature-humidity control system of the test chamber

The steady state temperature-humidity test and the temperature-humidity cyclic test may be made using the same equipment. The test chamber may be classified into the following types by the humidity generating systems.

a) Direct type (balanced humidity control)

Humidity is increased when the humidity of the chamber is less than the test humidity condition and dehumidified if the humidity is higher than the specified value. It is possible to obtain stable humidity conditions by balancing humidification and dehumidification. It is usually possible to set a wide range of humidity levels, and the response time is very fast to a change of setting conditions or to variations of load (specimens). It is also possible to set a complicated test condition. This type of humidity controller is most widely used.

b) Two-temperature type

First cool the air in the chamber to the dew temperature of the humidity at which a test is made to make the air to saturated vapour pressure, and then heat the air to the temperature and humidity of the test condition. There are several methods to obtain saturated humid air. The most commonly used method is to shower the air and pass the air through water by bubbling. It is possible to obtain stable and accurate humidity in this system but response time to condition changes is inferior to the direct method.

3) Remarks on the test equipment

a) A thermal insulation material is used for the outer wall of the test chamber to attain better thermal insulation. The performance of the insulation material used in the test chamber deteriorates after the use of the chamber for a long time, due to the absorption of water vapour inside of the chamber, and there is a case of dew formation on the inside wall of the chamber. Replacement of the inside wall and thermal insulation of the wall of a chamber are necessary in such a case.

b) The inside environment of the test chamber may be affected by the environment the equipment is installed in as the air in the room is directly fed into the chamber in the case of steady state temperature-humidity test. Air contamination in the room may affect the test results if there are some corrosive gasses such as chlorine, hydrogen sulfide or others alike. The test equipment should be installed in good air conditions.

4.2.4 Remarks on testing

The steady state temperature-humidity test and cyclic temperature-humidity test are made as specified in relevant standards but these standards described do not state the detailed know-how of the operation of a test. Some of the know-how of test performance is given here:

1) Wick

a) Deteriorated wick and exchange of wick

A dry and wet bulb hygrometer is usually used in the present steady state temperature-humidity test chamber. It is necessary to supply water to the wet bulb by means of a piece of cloth such as gauze (called wick). The wick may deteriorate after being used a long time and its colour may change. Such a deteriorated wick may affect the humidity measurement and the experimental results.

It is usually necessary to change a wick once a month. However, it is better to change a wick when the equipment is not used for a long time or the wick replacement history is uncertain.

b) Cleanliness of the wick in the market

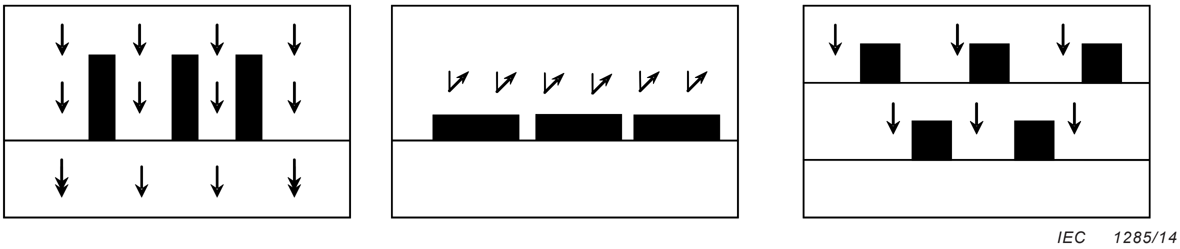
Table 8 shows the result of the ion chromatography analysis of wicks obtained in the market. Some wicks contain a high concentration of contaminations. Some antibacterial wicks are treated with chloride chemicals to avoid contamination by germs. A clean wick should be used in a measurement of insulation deterioration.

Table 8 – Ionic impurity concentration of wick (10^{-6})

Specification	Na^+	NH_4^+	K^+	Cl^-	PO_4^{3-}	SO_4^{2-}
General	229	3	210	13	6	14
Antibacterial treatment	28	5	6	638	82	39

2) Position of specimens in the test chamber

Air in the chamber is force circulated using a fan to keep the temperature and humidity in the chamber at the steady state. The air flow is obstructed by the presence of the specimens in the chamber. The positions of specimens should be carefully considered in order not to obstruct the air flow in the chamber, considering the air flow in the chamber as illustrated in Figure 14 a) and b). The position as illustrated in Figure 14 c) should be taken in case the number of specimens is large.



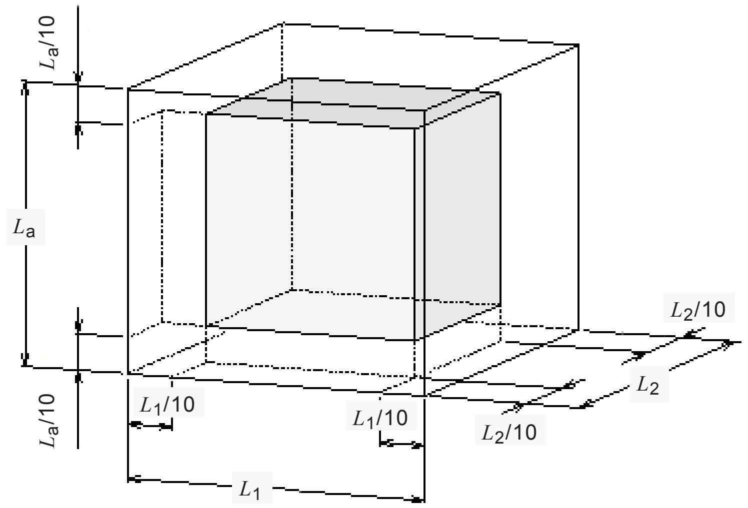
a) Good ventilation

b) Poor ventilation

c) Sample arrangement in case of a high number of specimens

Figure 14 – Specimen arrangement and air flow in test chamber

There may be an appreciable temperature difference at the centre and at the inner wall of the chamber. A working space is defined for a steady state temperature-humidity test. Appropriate space in a chamber is illustrated in Figure 15 for a rectangular or a cubic chamber. An appropriate space for a chamber is in the range excluding 1/10 of the distance between facing walls as shown in Figure 15. Temperature deviation may be greater outside of this effective space and test specimens should be placed within this space in the chamber.



Volume (l)	Minimum value of L_1, L_2, L_3 mm
Up to 1 000	50
1 000 to 2 000	100
More than 2 000	150

IEC 1286/14

Figure 15 – Effective space in a test chamber

3) Sealing of cables feeding into the chamber

   The cable protruding into the chamber should be firmly sealed so as not to leak the air in the chamber to the outside. Vapour may leak and the dew formed on a cable may also leak outside of the chamber if the sealing of the cables is not properly made.

4) Maintenance of the water quality of the water level controller of a steady state temperature-humidity test chamber

   It is necessary to clean the bottom of the water pan of a humidifier of the chamber and the water level controller of a wick pan constantly. Water is not supplied constantly to the level controller of the wick pan and the chance of growing weed in the wick pan is somewhat higher than the water pan of the humidifier. A water mixing fan in some water level controllers is equipped at a lower position in a pan and the water temperature may rise. Chance of weed growth is higher in such a case. The water pan of a humidifier may have concentrated impurities in water and may damage the heater in it. The heater should also be cleaned periodically.

5) Removal of specimens from the test chamber after the test

   Specimens are kept in a high temperature and high humidity environment in a steady state temperature and humidity test. Dew may develop on the specimen surface when specimens are taken out of the chamber. It is advised to keep the specimens for some time (1 h to 2 h) at 50 %RH and then to take them out for measurement.

4.3 Unsaturated pressurized vapour test or HAST (highly accelerated temperature and humidity stress test)

4.3.1 Purpose and outline of the test

The high temperature high humidity steady state test (unsaturated and pressurized vapour) specifies an environmental test applying a voltage to a printed wiring board at a high temperature and high humidity steady state condition in JPCA ET 08. This test is prepared to evaluate accelerated insulation degradation, resistance to migration, comparison of the characteristics of board materials, resistance to humidity of the insulation film (such as solder resist), and other characteristic deterioration of materials.

A HAST test is defined by JESD22-A110. It is a test with a high humidity environment performed at a temperature higher than the boiling temperature of water to accelerate material degradation as described in 4.2. Water is absorbed into a specimen very rapidly in an environment of high temperature, high humidity and high pressure.

This test was originally developed as a corrosion test of semiconductor devices. This test was also introduced to evaluate electronic materials of high quality recently developed and used together with semiconductor devices as the conventional steady state test at 85 °C and 85 %RH requires a long time to develop appreciable degradation. A test for some material characteristics such as resins for glass transition temperature, T_g, and some other materials to be tested should also be considered.

The JPCA ET 08 states that "This test is designed to obtain results with higher deterioration acceleration. This test was originally developed to test semiconductor devices mounted in a package. The high temperature specified in this test may affect the life of the specimen considerably depending on the glass transition temperature of the resin tested and the test temperature. If the relationship of the acceleration factor of life between this test and the practical use is not clear, this test should be for the quality assurance of a product, but for a comparative evaluation of the product.

4.3.2 Temperature-humidity-pressure profile

The test profile is described based on IEC 60068-2-66 and EIAJ ED-4701/102 (high temperature high humidity bias test) shown in Figure 16. The profile of the HAST is basically the same as that of the steady-state temperature humidity test. The temperature of the test chamber is first raised and then the humidity is raised. At about 100 °C, the chamber is saturated with water vapour and air is driven out. The air valve is closed and the chamber temperature is raised to the test temperature and the inside pressure increases.

When a HAST equipment is switched on not with the programmed control but with the ordinary steady state temperature humidity test profile, the profile of the test may be different from the one shown in Figure 16.

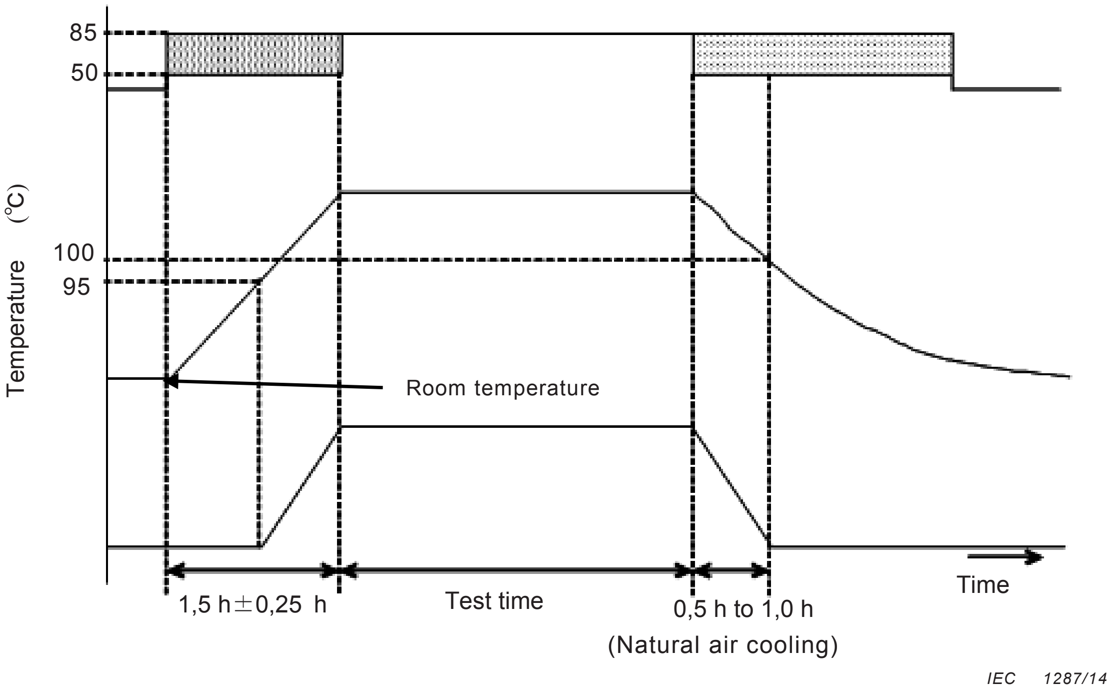
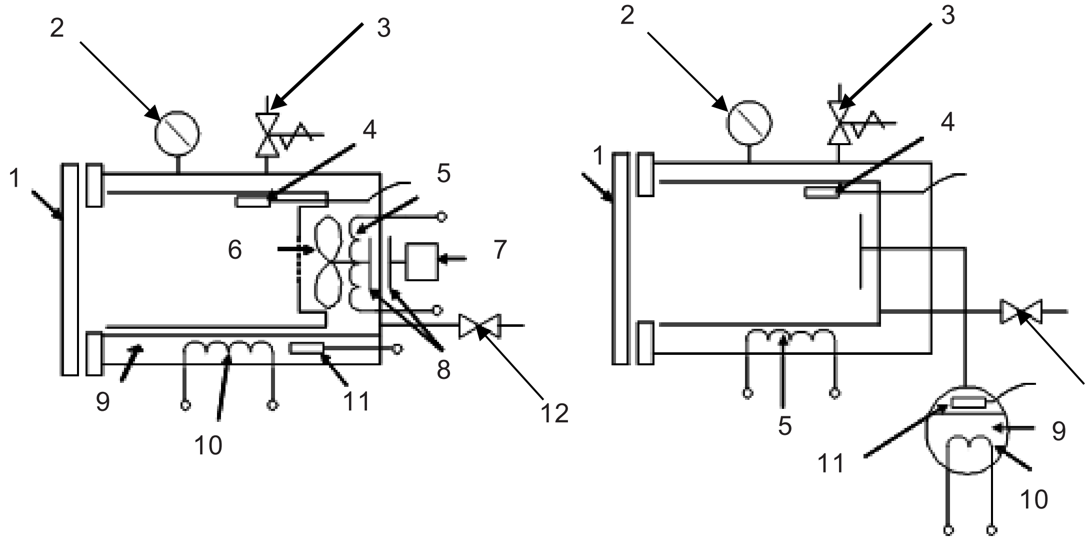


Figure 16 – HAST profile

4.3.3 Structure of and remarks on the test equipment

1) Structure of test equipment

   A typical structure of a HAST equipment is illustrated in Figure 17. There are two types of equipment: single-vessel and dual-vessel. The single-vessel type equipment has a fan for water vapour circulation. The speed of vapour circulation in the chamber is about 0,3 m/s, comparable to natural convection in the chamber. The water vapour vapourized from the bat placed at the bottom of the chamber is heated just before being sucked by the fan to a temperature higher than the surrounding water vapour and sent into the test chamber. Water vapour passing through the chamber is reflected at the door of the chamber and cooled while passing through the gap between the inner chamber and the wall of the pressurized chamber. Part of the vapour is condensed to water and drops to the water pan, and the water is again vapourized from the pan to supply the necessary water vapour. The dual-vessel type test equipment separates the test chamber and water vapour generation chamber to reduce temperature interference between the vapour generation chamber and the test chamber. This system does need to install the vapour circulation fan.



IEC 1288/14

a) Single-vessel type **b) Dual-vessel type**

Key

1. Door
2. Pressure gauge
3. Safety valve
4. Temperature sensor for moisture
5. Heater for moisture
6. Fan
7. Fan for air
8. Magnetic coupling
9. Humidifying water
10. Heater for humidifying water
11. Temperature sensor for humidifying water
12. Air exhaust valve

Figure 17 – Two types of HAST equipment and their structures

2) Remarks on the test equipment

   HAST is very sensitive to test conditions such as the setting accuracy of temperature and humidity and the cleanliness of the test chamber as it is a highly accelerated test compared to conventional steady-state temperature-humidity test. It is very important that the test condition should be reproducible to its best condition. Some cases are described below based on the study made by the Study Group of the Accelerated Life Test of the JIEP.

   a) Difference in failure time among different test equipment

      A study was made of test results of different materials at different test laboratories. Different failure times were found for different tests as shown in Figure 18. Temperature and humidity were in the same range and no meaningful difference could be found but the failure time varied considerably. The cleanliness of the test chambers and the aging of the chambers may be a possible reason but no specific reason was found. It is important in HAST to maintain the test system in good condition, otherwise the data obtained may not be very reliable.

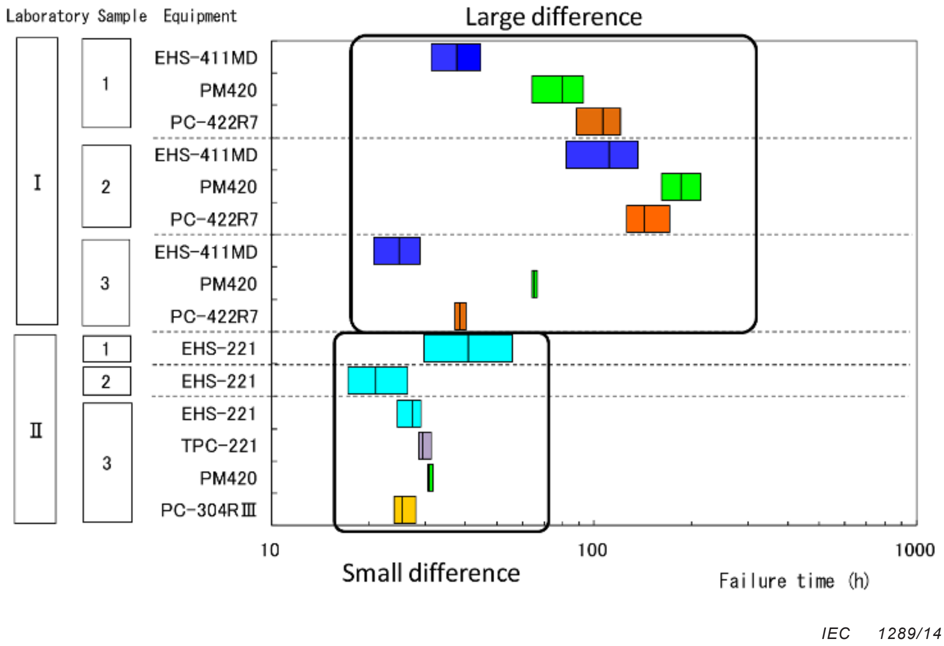


Figure 18 – Difference in failure time among different test laboratories

b) Effects of environment and of residue air of the test chamber

The HAST test chamber has a structure such that the air valve is open until the chamber is filled with water vapour at close to 100 °C to drive out the remaining air until the test environment in the chamber is established. The air valve is closed when the inside of the chamber is saturated with water vapour and its temperature is further increased to the test temperature at a higher pressure. The environment is not necessarily pure water vapour as there may exist some gases resolved in water and coming from the specimens.

An evidence of residue air in the chamber is the colour change of the specimens (boards). Figure 19 is an example of the study made by the Study Group of JIEP. The difference of colour of the boards may be caused by oxidation of the board surface in the chamber due to different degrees of contamination in the chamber, temperature rise speed, or different exhausting timing of air from the chamber. No clear correlation was found between the life and the colour change of the specimens. It is recommended to check the temperature and humidity in the chamber if they are within the predetermined range if the colouring of the specimens is significant.

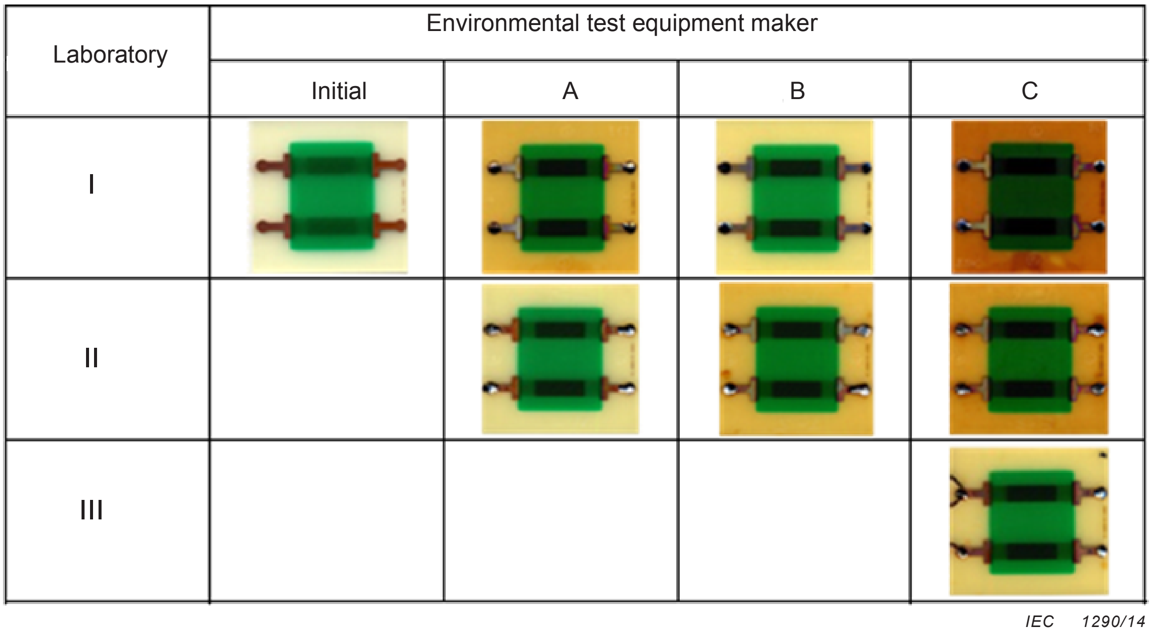


Figure 19 – Colour difference of specimen surface among different laboratories (130 °C/85 %RH/DC 50 V)

4.3.4 Remarks on performing HAST

1) Selection and maintenance of voltage applying cables

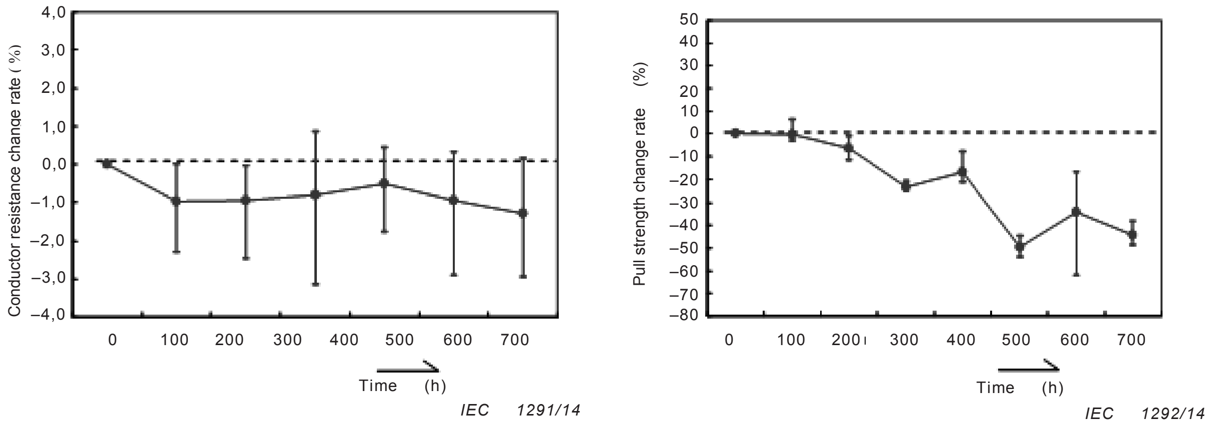
Table 9 shows materials and the heat resistance of cables in the market and used in voltage applying tests for high humidity tests. Cables with low hydrolysis and out-gassing are recommended for use in HAST environment. The surface of a cable may not be damaged after being used in HAST for a long time but cracks may be generated in the conductor and cable resistance may be increased.

Figure 20 shows an example of change in conductor resistance of a single wire cable and the pulling strength of such a cable. Cable resistance does not change significantly but the pull strength decreased appreciably after used in a high temperature-high humidity environment. It is recommended to exchange cables after use of 300 h each.

There are two types of cables, single wire cables and stranded wire cables. Degradation of cables may be different for these different types of cables. Cables used in HAST should be carefully checked.

Table 9 – Insulation covering materials for cables for voltage application

Type of covering material		**Max. temperature for continuous use** (°C)
Type	**Material**	
Fluoroplastics	PTFE	260
	PFA	260
	FEP	200
	ETFE	150
Polyethylene	Bridged polyethylene	90



IEC 1291/14

IEC 1292/14

a) Conductor resistance **b) Pull strength**

Figure 20 – Resistance and pull-strength of cables used in HAST (130 °C 85 %RH)

2) Installation of specimens in a HAST chamber

   HAST equipment is usually equipped with a propeller type fan to circulate vapour in the chamber to keep a constant temperature and humidity distribution, but the environment is not necessarily uniform in temperature and humidity. The guarantee of a constant temperature-humidity range by the equipment manufacturers is within over 1/10 of the inner walls of the chamber as illustrated in Figure 15. The presence of too many specimens or a specimen touching the chamber wall may disturb the temperature-humidity distribution in a chamber. When a specimen touches the wall, water drops may fall on the specimen or dew may form and disrupt the test results.

3) Other remarks

   a) The racking material used for the specimen and the door of the chamber should be selected so that it does not decompose or generate free ions during the test and it should have sufficient heat resistance at the test temperatures.

   b) A wet bulb in a steady-state temperature-humidity test equipment is supplied in water through a piece of gauze called wick. The wet bulb in HAST equipment is installed in the water pan. If the water in the pan is contaminated, the contamination may move to the surface of the wet bulb and may not indicate the correct humidity in the chamber. It is necessary to clean the surface of a wet bulb periodically.

   c) The key difference between the HAST equipment and the steady-state temperature-humidity equipment is that a HAST system is a completely closed system to realize an environment with a temperature higher than that of the boiling point of water. The gas released from the specimens remains within the chamber and is not discharged outside of the chamber. The gas is combined (absorbed) with water and stays on the chamber wall. The adherence of such contaminated water to the surface of the wall may lead to contamination of the specimens and may give incorrect test results. It is necessary to clean the inside wall of a chamber after a HAST test using alcohol.

   d) An independent heating source is installed in the heating and the humidifying systems with a sheath heater. The humidity control heater is immersed in water and vulnerable to humidifying water. Use of city water from the tap may significantly reduce the life of the sheath heater as city water contains chlorine and calcium hydroxide. It is advised to use the water at the purity the manufacturer of the equipment recommends, usually distilled water as described in 4.7, item 2).

   e) It is recommended to perform a calibration of the control sensor of the chamber of the HAST equipment once a year.

   f) A specimen should be sufficiently preheated if the specimen is of a large thermal capacity for dew formation protection.

4.4 Saturated and pressurized vapour test

4.4.1 Purpose and outline of the test

The saturated and pressurized test is basically similar to HAST but with 100 %RH and without applied voltage. This test is generally called PCT (pressure cooker test). This test is mainly used to evaluate the corrosion of the metallic parts of a product.

The test condition of PCT is similar to the sterilization processing condition of medical instruments. The corrosion test by the pressurized water vapour method started with the saturated type test, but this method had some problems, such as an effect of dew drops and reproducibility of failures found in products used in the field. The unsaturated type test is now widely used.

4.4.2 Test profile

After the temperature of the test chamber has reached the test temperature, the humidity is increased until the test condition is reached. Temperature and humidity are then maintained at the test condition.

4.4.3 Remarks on test performing

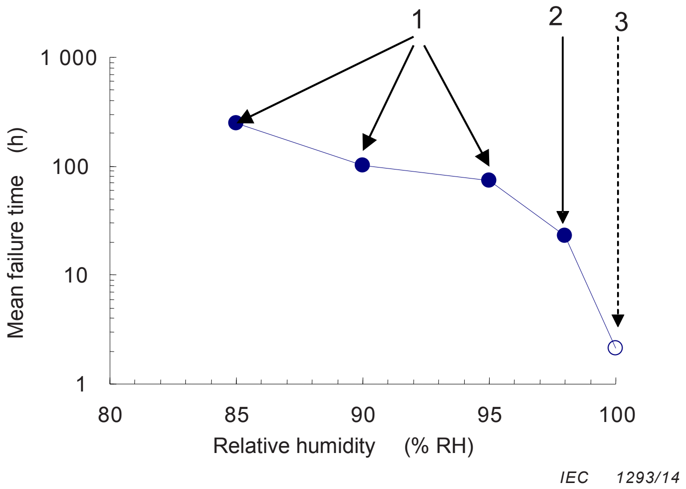
PCT is basically the same as HAST but with a special condition of relative humidity of 100 %. Below are specific remarks on PCT.

1) Maintenance of cleanliness of the chamber
   a) PCT is performed in an environment of relatively higher humidity than HAST. The test chamber may be contaminated considerably as a test is made in an environment of high relative humidity compared to HAST; it is necessary that the chamber be thoroughly cleaned, including the sensor and inner wall. It is reported that after the return of the temperature of the chamber to room temperature, the saturation water is replaced after washing the chamber with the aid of a brush and two cycles of saturation operation at 130 ° C, 100% RH, for 2 h, followed by the replacement of the saturation water to effectively remove the contaminants that were attached to the inner wall of the test chamber.
   b) When the equipment is used for both PCT and HAST, electric connecting terminals are vulnerable to corrosion. It is necessary to check whether the electrical connection is in good condition by checking the terminal connection resistance when using the equipment for HAST after using it for the PCT.
2) Installation of specimens in the chamber

   Dew formation on the surface of a specimen may vary by the position of the specimen setting. The best specimen position may be found according to the purpose of the test.
3) Coexistence of both saturated and unsaturated humidity control environments

   There are two types of tests, for the saturated humidity of 100 %RH (the so-called auto-clave state) and the dry-type (humidity is controlled at 98 %RH to 99 %RH). Both of them are called PCT. Both tests can be performed using the same equipment and the proper control system. Figure 21 shows the test results for these two conditions with an applied voltage. The failure time difference in these two conditions is clearly observed at nearly 100 %RH (a difference of about 1/10 times shorter). It is important to clarify in which condition the PCT is made.

   PCT was once standardized by the EIAJ (Electronic Industries Association of Japan) but was withdrawn as the relation between the test results and failures in the field was not clear. The test is still used by many at the request of users of electronic devices. PCT gives quite different results, as stated before, due to the condition of saturation (100%RH) or almost saturation. We do not have a standard for this test and no agreed test condition. Should one perform the PCT test, details should be agreed upon by the user and supplier concerned.



Key

1. Unsaturated condition at 121 °C
2. Almost saturation in PCT control method at 121 °C
3. Saturated control (auto-clave) in PCT control method at 121 °C

Figure 21 –Difference between unsaturated and saturation control of PCT equipment (relative humidity and average failure time)

4.5 Dew cyclic test

4.5.1 Purpose and outline of the test

The dew formation test tests devices which are used in products having quite a severe field condition of considerable temperature changes encountered in, for example, mobile devices or electronic components used in automotives. Quite a temperature change may be experienced when a product is brought from a cold outside environment into a heated room (or vice versa) and dew may be formed on the surface of such equipment. A dew cycle test makes it possible to evaluate the accelerated insulation degradation and migration by dew formation, and is used for reliability evaluation of conductor patterns on printed wiring board or surface treatment.

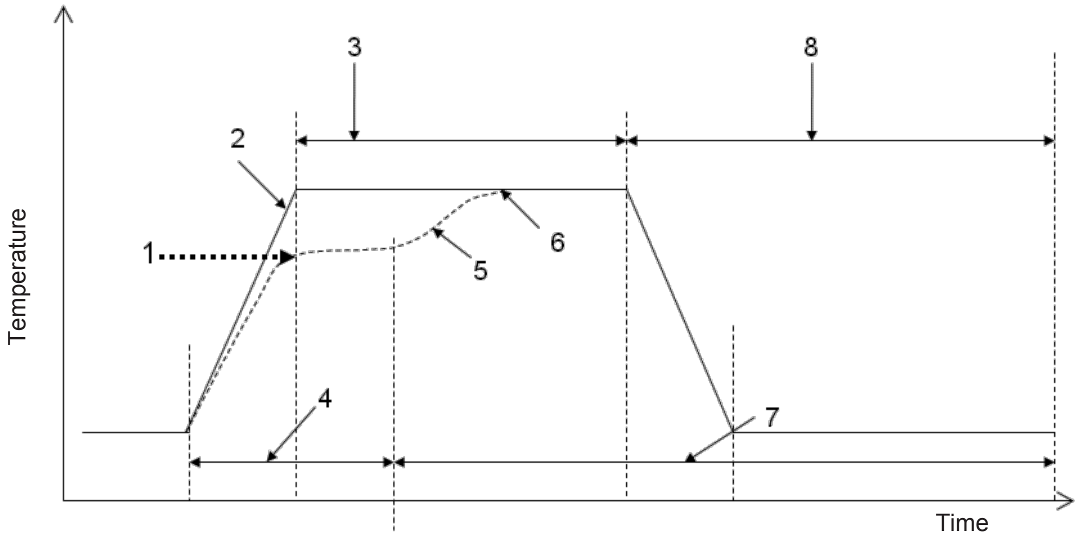
4.5.2 Dew cycle test temperature-humidity profile

Table 10 shows the test condition of a typical dew cycle test and Figure 22 shows the temperature-humidity profile. When a specimen is exposed to high temperature, its environmental temperature first increases rapidly and follows the rise of the surface temperature of the specimen but its temperature rise is delayed. Dew forms when the surface temperature reaches the dew point and then the dew begins to evaporate as there is not 100%RH. The surface temperature of the specimen is about the same as that of the wet bulb in an environment around the specimen. The specimen temperature increases after the dew evaporates to the temperature of the environment surrounding the specimen.

It should be noted that the temperature-humidity profile of a temperature difference of about 20 °C should be selected as the dew cycle test may be affected if the temperature difference between high and low temperatures is large.

Table 10 – Dew cycle test condition

Group	STD no.	Title	Test condition				
				Zone			
				t_1	t_2	t_3	t_4
JPCA	ET 06	Dew cycle test	1	5 °C /60 %RH 20 min	≤ 20 s	25 °C /90 %RH 20 min	≤ 15 min
			2	0 °C, 25 min	≤ 20 s	30 °C /90 %RH 25 min	≤ 15 min
			3	–5 °C, 30 min	≤ 20 s	35 °C/90 %RH 30 min	≤ 30 min



IEC 1294/14

Key

1 Dew point temperature
2 This curve represents the test area temperature
3 High temperature period
4 Dew point period
5 This curve represents the specimen surface temperature
6 Wet-bulb temperature and dry-bulb temperature become the same temperature
7 Drying period
8 Low temperature period

Figure 22 – Temperature-humidity profile of dew cycle test

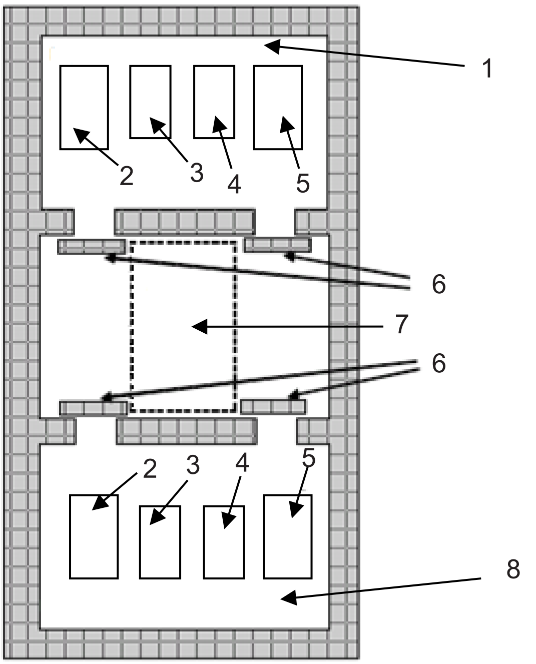
4.5.3 Structure of the test equipment

Construction of the dew cycle test equipment is shown in Figure 23. The low temperature chamber and the high temperature chamber are set to the predetermined condition. A very rapid temperature and humidity change is given to a specimen by moving the dampers in the test chamber to be connected from the low temperature-low humidity chamber to the high temperature-high humidity chamber. Dew formation is repeated by opening and closing the relevant dampers.

4.5.4 Remarks on the test method

1) Volume of dew
   a) Temperature difference and size of dew drops

      Dew is formed in the process of temperature change of the specimen from low temperature to high temperature as the specimen temperature cannot follow the temperature change of the environment. Dew is formed at any temperature range when the environment temperature changes from low to high. The size and weight of a dew drop are different for different environment temperatures even for the same temperature difference (Figure 23).



IEC 1295/14

Key

1 High temperature and humidity chamber
2 Humidifier
3 Air conditioner
4 Heater
5 Blower
6 Damper
7 Test area
8 Low temperature and humidity chamber

Figure 23 – Structure of dew test equipment

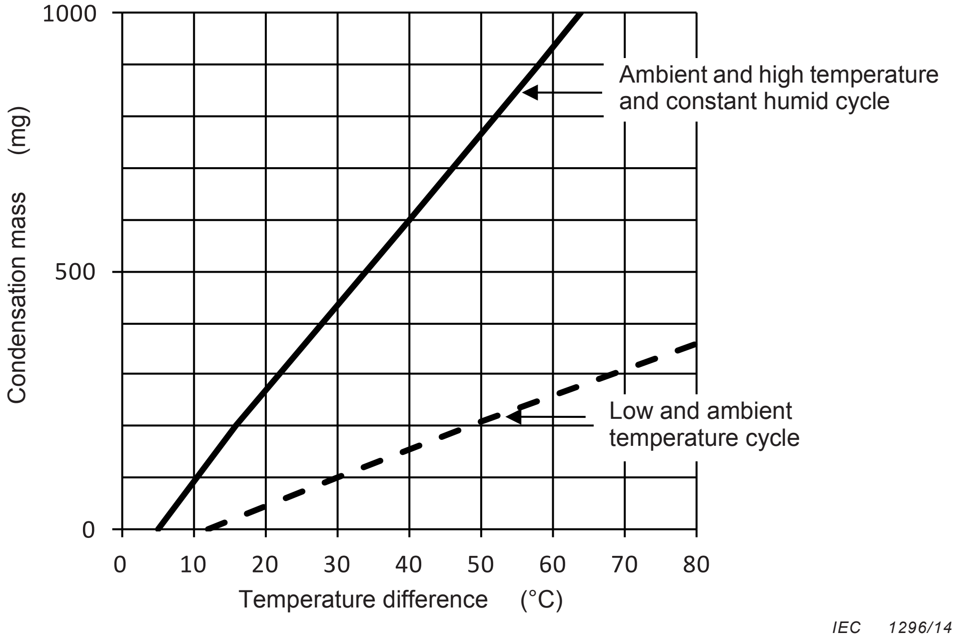


Figure 24 – Dew-forming temperature and dew size

b) Control of dew formation

  i) Dew formation depends on the test condition and the time to expose a specimen to the environment. It is the prerequisite of a test that reproducibility is attained for the amount and the time dew exists on a specimen. It is necessary to have a stable control of the environment and an accurate measurement of temperature and humidity.

  ii) It is very difficult to measure the amount of dew formed. It depends on the thermal capacity and amount of water vapour absorbed. One should be very careful in designing the material of the specimen and its structure. It is especially important for a relative comparison test of the different specimens.

2) Other remarks

  a) The passage of cables into the test chamber should be hermetically sealed to keep the airtightness of the chamber as described in 4.2.4, item 3).

  b) Cables for power supply and connections to a specimen are sagged so as not to give mechanical stress to a specimen and also so that the dew condensation water does not directly drop to the specimen.

  c) Cables used in the equipment should be thermally resistive to the high temperature of the equipment environment.

  d) If the equipment door is opened during the experiment, the air of the high temperature and high humidity leaks out of the chamber and is very dangerous. If the door is opened right after the measurement, one may get burnt.

  e) A small specimen or a light specimen should be covered by an aluminium basket, a net or a bag so as not to be removed or blown away by the circulating air in the chamber.

3) An example of dew cycle test

There is no specified procedure to determine the best dew formation condition. One of the practiced procedures is described below.

Procedure:

  a) Selection of the environmental mode of dew formation (room temperature to high temperature, and low temperature to room temperature).

   b) Confirmation of dew size for the test temperature combination (low environmental temperature, high environmental temperature/humidity).

   c) Decide the best dew formation condition from the relation between the size of the dew drop and the space between the conductor pattern lines.

4) An example of a study of the best dew formation condition

   A study of dew drop size was made with the conditions shown in Table 11 to determine dew formation condition that a dew drop is densely distributed without contact with two conductor lines in the neighbourhood of a dew drop using FR-4 printed wiring board. Figure 25 shows the dew formed by the best dew formation conditions. Dew drops are densely present in conductor spaces but do not touch the two conductor lines. Dew formation condition for this case is 5 °C to 25 °C at 95 %RH.

Table 11 – Dew formation condition and dew size

Condensation condition	Water droplet size	Water droplet occupation rate between conductors
0 °C to 20 °C, 95 %RH	0,13 mm	35 %
5 °C to 20 °C, 95 %RH	0,08 mm	20 %
5 °C to 25 °C, 95 %RH	0,13 mm	38 %
20 °C to 40 °C, 95 %RH	0,40 mm	95 %
20 °C to 60 °C, 95 %RH	0,50 mm	100 %

NOTE 1 The gap between conductors is 0,318 mm.

NOTE 2 Water droplets cross the gap when the occupation ratio is 40 % and above.

IEC 1297/14

Figure 25 – Board surface at the best dew formation condition

4.5.5 An example of migration in the solder flux from the dew cycle test

1) Experiment

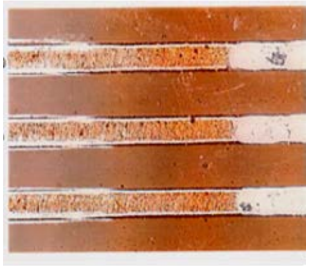
   Migration was tested in a comb type conductor pattern covered with solder flux at the best dew formation condition shown in Table 12.

Table 12 – Dew cycle test condition

Environmental condition	5 °C to 25 °C, 95 %RH
Test cycle	40 cycles (about 27 h)
Test design	Comb type pattern in conformity with IPC
Substrate material	FR-4
Flux	RMA type
Applied voltage	DC 50 V

2) Result

Figure 26 shows the surface of a specimen before the experiment. The insulation resistance was $5 \times 10^7\ \Omega$ but decreased to $6 \times 10^4\ \Omega$ after a test time of 27 h and migration was found on the surface as shown in Figure 27.



IEC 1298/14

Figure 26 – Surface state before test

IEC 1299/14

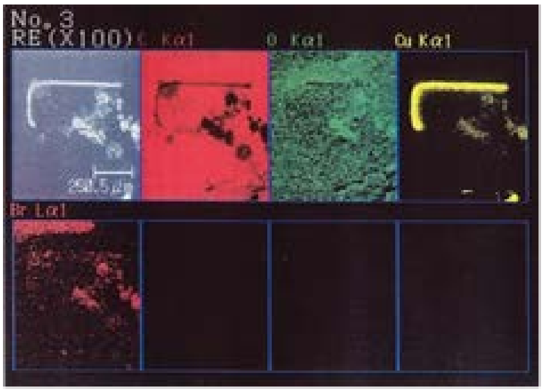
Figure 27 – Surface state after 27 h

3) Failure analysis (including failure mechanism)

The generation of a crack was observed by SEM observation on the surface in the residue of the solder flux after 27 h of the dew cycle test as shown in Figure 28. An element analysis of the surface revealed presence of copper, the material of the conductor along the flux residue as shown in Figure 29. It is considered that the copper migration is the source of the insulation degradation. The failure mechanism elucidated from this study seems to be that the flux residue was cracked and water entered into the crack, causing copper ion migration and resulted in insulation failure in a short time. No such insulation degradation was observed when a similar specimen was left in an environment of 40 °C/95 %RH for 2 000 h, and no crack in the residue was observed.

IEC 1300/14

Figure 28 – SEM image of specimen surface after the test



IEC 1301/14

Figure 29 – Element analysis of the surface after the test

4.6 Simplified ion migration tests

4.6.1 General

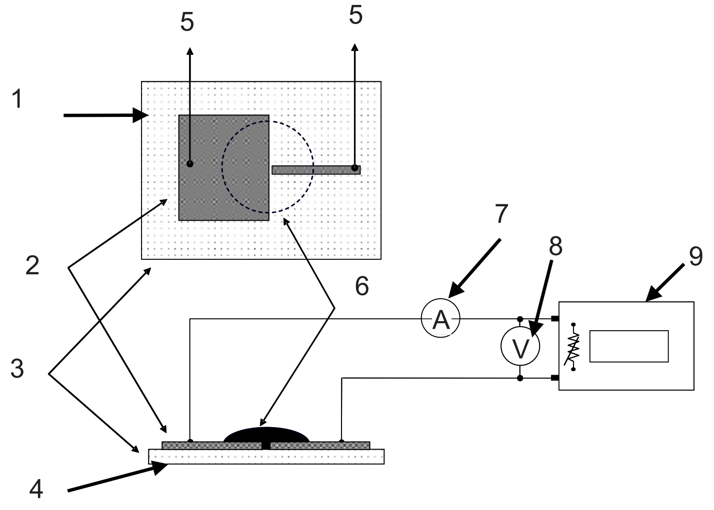
Sophisticated equipment is needed, in general, for migration tests as heating and humidifying of the test chamber environment is necessary, and a somewhat long time is required. There are two preliminary simplified test methods for a humidifying evaluation. These kinds of tests may be made as a preliminary test to evaluate test conditions before performing a real evaluation test of conductor materials, insulation materials, or covering materials such as solder resist. One is the de-ionized water drop test and the other is the diluted solution test.

4.6.2 De-ionized water drop method

This test method consists in dropping de-ionized water drops of very high insulation resistance to a facing pair of electrodes and in measuring the insulation resistance between these electrodes.

1) Measurement

   The circuit diagram of the de-ionized water drop test is shown in Figure 30.



IEC 1302/14

Key

1	Top view
2	Electrode
3	Substrate
4	Side view
5	To power supply
6	Water drop
7	Ammeter
8	Voltmeter
9	Power supply

Figure 30 – Circuit diagram of water drop test

2) Specimen

The specimen is a printed wiring board with a conductor pattern on it. A gap is formed between the conductors. L'équipement sophistiqué est nécessaire, en général, pour les essais de migration. Selection of the specimen type is based on the material of the specimen. Either type of gap may be selected.

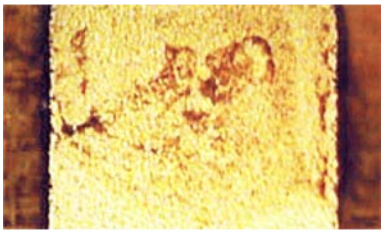
3) Test procedure

a) Prepare de-ionized water of resistivity greater than 10^6 Ω cm.

b) Drop water drops to cover the conductor gap using a pipette.

c) Connect the electrodes to a power source and apply a specified voltage for a specified time. Measure the current through the conductors.

d) The specimen is water-cleaned and dried. Observe the appearance of the gap. An example of migration is shown in Figure 31. Comparison of the gap condition and the leaking current is used for the evaluation of the degree of insulation between the gap.



IEC 1303/14

Figure 31 – Migration generated in the water drop test

4) Remarks

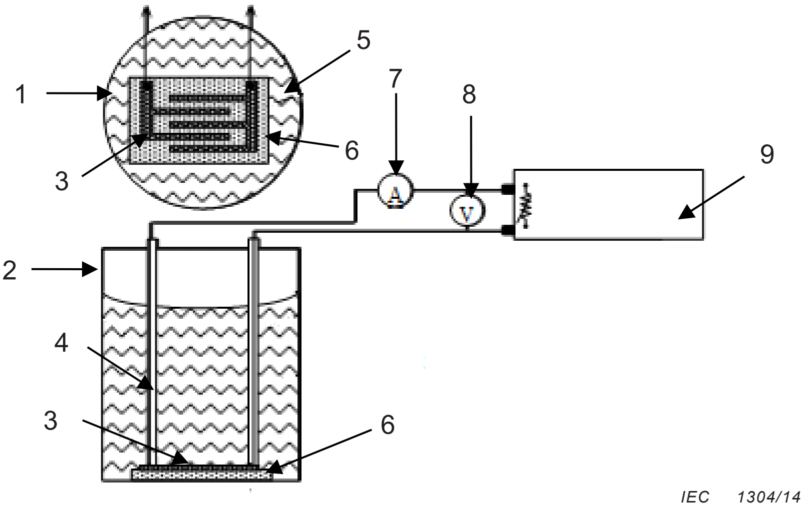
De-ionized water is highly purified water with a high resistivity. If left in the air, the de-ionized water may absorb CO_2 gas in the air and other water-soluble board contaminating substances, and may decrease insulation resistance between the conductors. Measurements should be made in a short time and new water drops should be used for each measurement.

4.6.3 Diluted solution method

This method uses water with a very small amount of ionic salt in which a specimen is immersed and a voltage is applied between conductors. Current flows between conductors and the degree of migration may be evaluated.

1) Measurement

The test diagram is shown in Figure 32 and is similar to the electroerosion test. The specimen is immersed in a diluted ionic salt solution.



Key

1 Top view
2 Side view
3 Electrode
4 Insulating coat
5 Weak electrolytic solution
6 Substrate
7 Ammeter
8 Voltmeter
9 Power supply

Figure 32 – Electroerosion test method using the diluted solution

2) Specimen

A comb type pattern is formed on an insulating board as shown in the upper illustration of Figure 32. Leads are soldered or welded to the electrodes and the leads and interconnections are covered by insulating resin so that the conductor and leads are not in contact with the diluted solution.

3) Procedure

a) Prepare a (10^{-6} to 10^{-7}) mol/l HCl solution of specified refined salt.

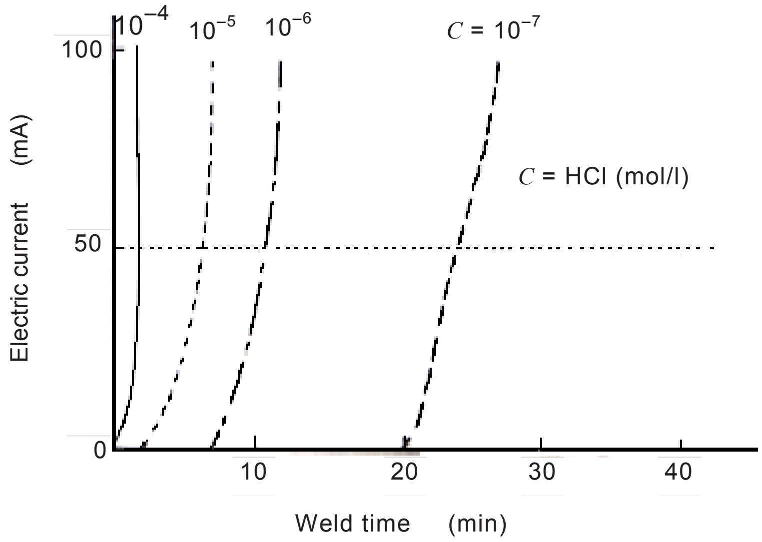
b) The specimen is immersed in a vessel with the solution and the specimen is connected to a power supply.

c) Apply a specified voltage to the specimen and measure the current. Stop the test when the current has reached a specified value.

d) The specimen is water cleaned and dried, and then the conductor gap is observed.

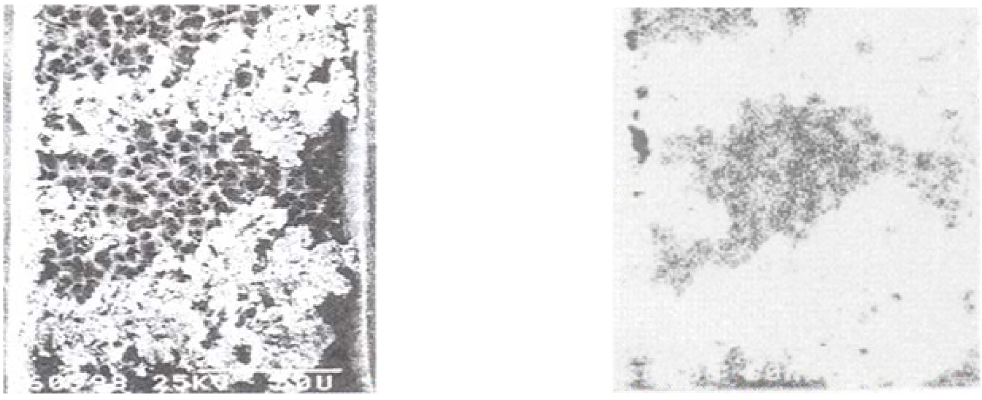
4) Example of a test result

Described here is an analysis of the diluted solution test. It is a preliminary and simplified test performed prior to an impurity ion migration analysis in the printed wiring board. Figure 33 shows current-time correlations for different concentrations of HCl solution. The time to start the current is longer for a low concentration of the salt. The proper concentration was decided to be around (10^{-6} to 10^{-7}) mol/l HCl solution. The observation of precipitation on the specimen at 50 mA is shown in Figure 34, a similar pattern to the migration pattern. It was decided that a preliminary test can be made using this method.



IEC 1305/14

Figure 33 – Current and concentration of electrolytic solution



IEC 1306/14

IEC 1307/14

a) Precipitation on a board

b) Analysis of precipitation copper (Cu)

Figure 34 – Precipitation on a specimen and its element analysis

4.7 Items to be noted in migration tests

1) Capability standard of steady-state temperature-humidity test equipment

IEC 60068-3-5 specifies the equipment for the steady-state temperature test and IEC 60068-3-6 for the steady-state humidity test. The Japan Testing Machinery Association (JTM) specifically described the capability test method and physical method to describe the performance of the temperature test chamber based on JTM K 07.

2) Water used in the test

The water used in the humidity resistance test is specified for its type, resistivity and dielectric constant as given in Table 13. De-ionized water is to be used in general.

Table 13 – Water quality for test

Standards organization	Standard number	Water quality
EIAJ	ED-4701/100	– distilled or de-ionized water – pH 6,0 to 7,2 at 23 °C, resistivity of more than 500 Ωm
IEC	IEC 60068-2-78	– resistivity of more than 0,05 MΩm
	IEC 60068-2-66	– distilled or de-ionized water – pH 6,0 to 7,2 at 23 °C,resistivity of more than 0,5 MΩcm (conductivity less than 2 µs/m)
JEDEC	JESD22-A101	– de-ionized water – resistivity of more than 1 MΩm at room temperature
IPC	IPC-TM-650	– distilled or de-ionized water – resistivity of more than 2 MΩcm

The important issue to be taken into consideration is the quality of the deionized water used in testing (concentration of ionic impurities). Table 14 shows the result of a study of ionic impurities checked by ion chromatography in water taken from various sources. Ionic impurity in water is in the following order: 1) tap water, 2) pure water, 3) ultrapure water. Ordinary pure water may be contaminated when it is kept in a reserve tank and may be more contaminated than tap water if it is left in room environment. The pure water used in the test should be introduced to the test chamber directly from the source to keep the time water is left in the room environment as short as possible.

It is possible to reduce contamination by cleaning the water pan in the test chamber and avoid damages to the heater caused by accumulated contamination. Do not use contaminated water and regularly clean the water pan.

Table 14 – Water quality change in steady-state temperature-humidity test (10^{-6})

Ion chromatograph analysis sample			Cation			Anion	
			Na^+	NH_4^+	K^+	Cl^-	SO_4^{2-}
Water quality	Ultrapure water		0,1	0,1	–	0,3	0,3
	Pure water	Immediately after extraction	4,6	1,2	1,1	8,4	5,7
		leaving in room (after a week)	51,4	203,4	31,3	58,2	5,7
	Tap water		12,0	–	1,8	10,3	–
Water quality change in moisture test	In tank		7,4	31,0	5,5	14,0	11,7
	In humidification water reservoir	Before cleaning	212,0	369,0	159,0	889,0	1 190,0
		After cleaning	14,0	206,0	8,0	86,0	110,0

3) Other components used in the humidifying test:

a) Types of jigs used to install specimens in steady-state temperature-humidity and HAST test chambers

The main fastening and test voltage applying jigs available in the market for the test are given in Table 15. PTFE (Polytetrafluorothylene) or resin material with equivalent heat resistance is used for the portion which fixes a specimen and serves as a specimen plug-in jig. Some special remarks on the jigs are given below.

i) Select a material which has higher thermal resistance and does not generate outgas so as not to affect the test result.

ii) Use metal parts which are resistive to erosion such as SUS (steel use stainless).

iii) It is difficult to use the specimen holding jig in both the steady-state temperature-humidity test and HAST test environments, because the test conditions such as test temperature, vapour pressure, the capacity of test chamber and the temperature rising profile at the time of the test start are different between the steady-state temperature-humidity test and the HAST test. It is important to select the most suitable specimen holding jig in accord with the test condition.

b) Ionic impurity concentration of the voltage applying cable used in a test chamber

The insulation cover of the cable used for voltage application to a specimen should have heat resistivity higher than the test temperature, and the covering material should be of the lowest possible ionic impurity (free ions) concentration. Ammonium ions for cation, and chlorine and sulfuric ions for anions are considered to be related to migration. Cover tubes and resin covers used for terminals should also be of low ionic impurity concentration. Table 15 shows the ionic impurity concentration found in voltage application cables available in the market.

Table 15 – Ionic impurities in voltage applying cables (10^{-6})

	NH_4^+	Cl^-	SO_4^{2-}
ETFE	0,07	0,45	0,20
Cross-linked polyethylene	0,85	0,77	0,42
Polytetrafluorothylene coating	0,14	0,93	0,08
Heat shrinkage tube	1,79	2,53	1,60
Terminal cover	0,28	1,91	0,21

4) Specimen installation in a test chamber

The direction of a specimen in a test chamber may not have significant effect. Convection in the chamber (dual-vessel type system) is caused by natural flow of air and vapour. However, a forced convection system (single-vessel type system) may influence the test results due to the direction in which a specimen is installed in the chamber. A specimen should be installed in a chamber as shown in Figure 14 so that the convection flow does not hit the specimen directly and prevents dew formation on the specimen's surface. Enough space should be left between the chamber wall and the specimen. The specimen should be parallel to the convection flow direction to not interfere with the flow.

5 Electrical tests

5.1 Insulation resistance measurement

5.1.1 Standards of insulation resistance measurement

Table 16 gives the available standards of insulation resistance measurement.

Table 16 – Standards of insulation resistance measurement

Standard no	Standard name	Measurement condition
JPCA ET 01	Printed wiring board environmental test method	– Test voltage and voltage: DC 5 to 100 V recommended – Insulation resistance measuring method: Measurement inside or outside of chamber – Measurement changing time: IPC J-STD- 004 – Acceptance value Measurement inside of chamber: $1 \times 10^6\ \Omega$ or more Measurement outside of chamber: $1 \times 10^7\ \Omega$ or more
IPC-TM-650:1979, 2.5.27	Surface insulation resistance of raw printed wiring board material	– Measured voltage: DC 500 V – Measurement is within 60 s – After 24 h at 150 °C measurement
IPC-TM-650:2004, 2.6.3.3B	Surface insulation resistance, flux	– Applied voltage to the device DC 45 V to 50 V ± 10 %V – Measured voltage DC 100 V
UL 796	Printed wiring boards (silver migration)	– Measurement condition Minimum distance 1,6 kV/mm (40 V/mil) Max 1 000 V Charging time 60 s – Test condition 35 % ± 2 %/1 344 h, rated voltage – After test 23 °C ± 2 °C/50 % RH/48 h measurement after neglect
ISO 9455	Soft soldering fluxes Test methods-Part17: Surface insulation resistance comb test and electrochemical migration test of flux residues	– Test condition 40 °C, 93 %RH or 85 °C, 85 %RH – Acceptance value under 100 MΩ ($1 \times 10^9\ \Omega$) – Test voltage DC 50 V – After test 25 °C, 50 %RH, 2 h measurement after neglect

5.1.2 Measurement method of insulation resistance

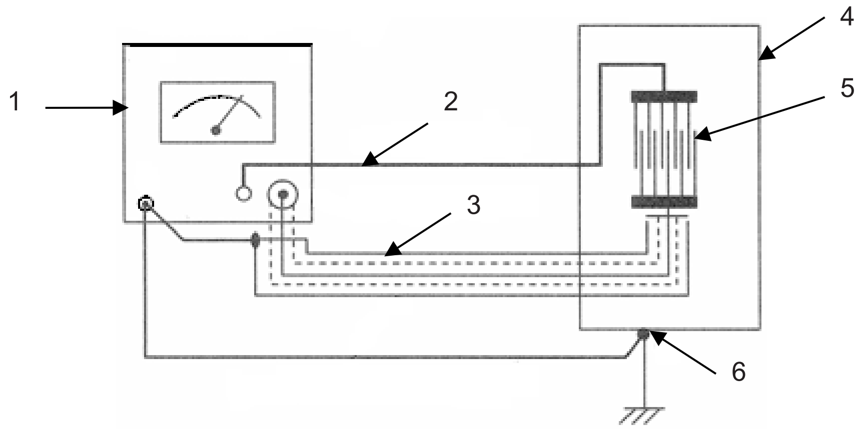
The insulation resistance measurement is commonly used to evaluate migration. There are two types of measurement, one is to measure the resistance of a specimen while it is taken out of the test chamber (measurement outside of the chamber), and the other is the measurement in situ condition while the specimen is kept in the testing environment and not taken out of the chamber for measurement (measurement in the chamber). The outside-of-the-chamber measurement is not a real insulation evaluation under the testing environment. Dew formation may occur when a specimen is taken out of the chamber after the chamber environment is brought to the outside environment. A specimen may change its characteristics by being taken out of the chamber into the outside environment. Measurement by not taking the specimen out of the chamber is usually recommended.

1) Outside-of-the-chamber measurement
   a) The chamber environment is first returned to the standard atmosphere condition and then a specimen is taken out of the chamber. The specimen is dried for a specified time and its

characteristics are measured within a specified time. All the measurements are made under the same temperature and humidity environment.

b) The sample extracted from the chamber is maintained in the standard atmosphere for a specified time. It is then stored in a shielded box to not be influenced by the magnetic field or electrostatic field caused by the human body, as illustrated in Figure 35, and its insulation resistance is measured. A specimen should be left on a base made of polytetrafluoroethylene resin which has a high insulation resistance, or in a floating condition in the measurement. Insulated covers should be used for the voltage terminals of the equipment so as not to touch the terminals with bare hands. Care should be taken not to touch the resin material in the vicinity of the conductor while the measurement terminal (clip or probe) is connected to the measuring conductor pattern.

c) Special care should be taken to use a glove so as not to touch a specimen by with bare hands. Spit should never be sprayed on the specimen surface.



IEC 1308/14

Key

1 Insulation resistance meter
2 Voltage
3 Shield cable
4 Shield box
5 Sample
6 Ground

Figure 35 – An example of insulation resistance measurement outside of the chamber

2) Measurement in the chamber

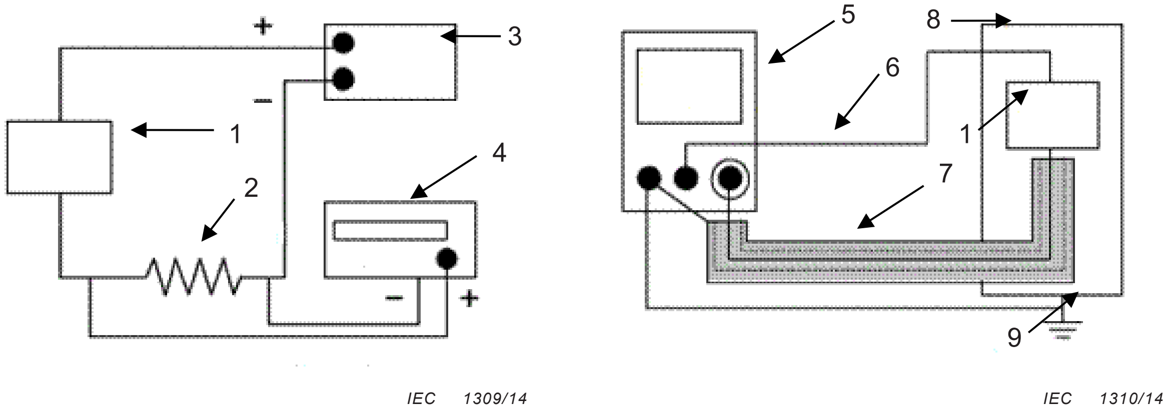
There is an automatic measuring system to measure of the insulation resistance of specimens using insulation resistors:

a) Principle

A current detecting resistor is connected to a specimen in a series and a constant voltage is applied to the circuit as illustrated in Figure 36 a). The current in the circuit is measured by measuring the voltage across the resistor. It is possible to measure the current continuously without interrupting the exposure of a specimen to the test environment. The measuring circuit may have an interference effect from other circuits and the number of wires increases if the measurement is made for many specimens. Care should be taken in the handling of cables.

b) Measurement using an insulation resistance meter

An insulation resistance meter as illustrated in Figure 36 b) is used to measure a high resistance to the order of 10^6 Ω to 10^{12} Ω. It is generally possible to measure a resistance to the order of 10^{13} Ω. The testing circuit is also used for the measurement so that the wiring of cables should be carefully made to an insulation resistance meter. A measurement system is available in the market to measure the insulation resistance of many specimens while the specimens are kept in a test chamber.



IEC 1309/14

IEC 1310/14

a) Measurement by voltage-drop method **b) Measurement by insulation resistance meter**

Key

1 Sample

2 Resistance for detection

3 Power supply

4 Voltmeter

5 Insulation resistance meter

6 Voltage apply cable

7 Shield cable

8 Constant temperature chamber

9 Ground

Figure 36 – Circuit diagram of insulation resistance measurement

c) Automatic measurement system

An automatic measurement system is usually used to avoid the complexity and inconvenience of cable wiring outside of the test chamber. The features of such an automatic system are described below.

i) Features of an automatic measurement system

Continuous measurement of insulation resistance is possible while a specimen is kept in a test chamber. An alarm can be ring when any abnormal effect is found in the measurement.

A test voltage is applied to each specimen and the leak current is continuously monitored for any arbitrary period of time. It is possible to identify the migration generation and its time. Basically there is no limit to the number of specimens to be measured in a single run. Simultaneous measurement of many specimens is possible.

ii) Automatic measurement systems available in the market have proprietary structures developed by manufacturers. Remarks on the selection of a system for laboratories are given below.

There is a possibility of having quasi-leakage of a specimen by water absorption. Equipment should have both high and low resistance, for the low range including measurement of $\langle 10^{6}\ \Omega$. The insulation resistance measurement range should include that of the measuring cables, including both ends of a cable.

Both specified and other additional test voltages should be able to be continuously applied. In the case of the system which can switch the test voltage and the measurement voltage, the overshoot of the applied voltage should be checked using an oscilloscope.

Migration in a conductor gap should be sensitively detected (an increase of the leakage current between conductors should be clearly detected).

Migration in one specimen may also affect leakage current in other specimen.

It is desirable to limit leakage current when migration occurs to avoid burn of resin in specimens.

5.1.3 Special remarks on insulation resistance measurement

1) Relationship between static charging and leakage current in insulation resistance measurement

In some cases the charging should be specified before measurement. The current through the specimen decreases with time (increase of resistance) and reaches a steady state current when a voltage is applied to a specimen. This decrease of current (increase of resistance) depends on the absorption current. Time before the current reaching the approximately constant value may take more than several hours from several seconds depending on the specimen. However, a rather short time is actually taken for ease of measurement.

The current flowing in a specimen is composed of a time independent leakage current by free electrons and free ions in the specimen, and the absorption current in dielectrics (charging) as shown in Figure 37. The dielectric absorption current is caused by the polarization of atoms, i.e. electric dipole formation. The current due to the movement of these electric dipoles in dielectrics is the dielectric absorption current.

This current may not decease uniformly in some materials and may not stabilize. The time of the measurement should be selected properly from the result of measuring the current-time relationship beforehand in such a case. It may take considerable time until the insulation resistance measurement value is stable especially for a product mounted on dielectrics such as capacitors as shown in Figure 38.

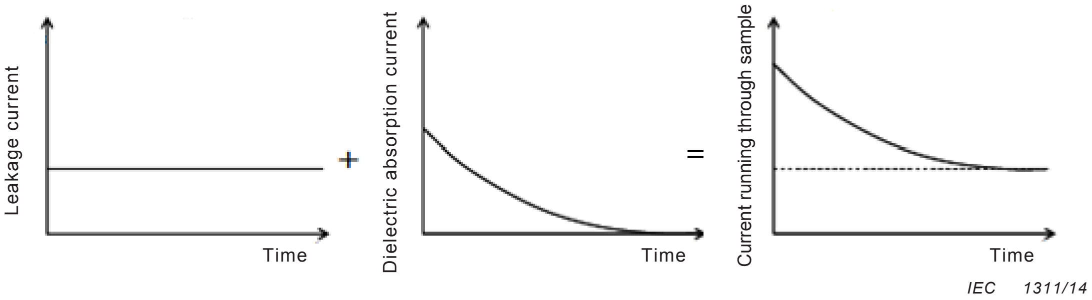


Figure 37 – Examples of leakage current characteristics

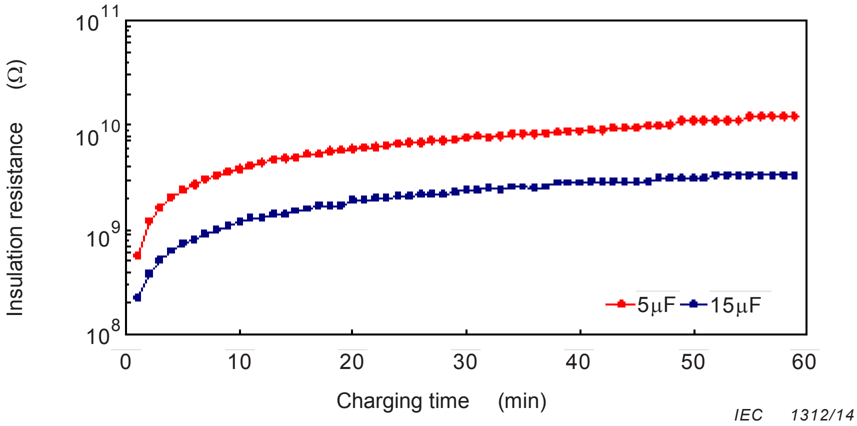
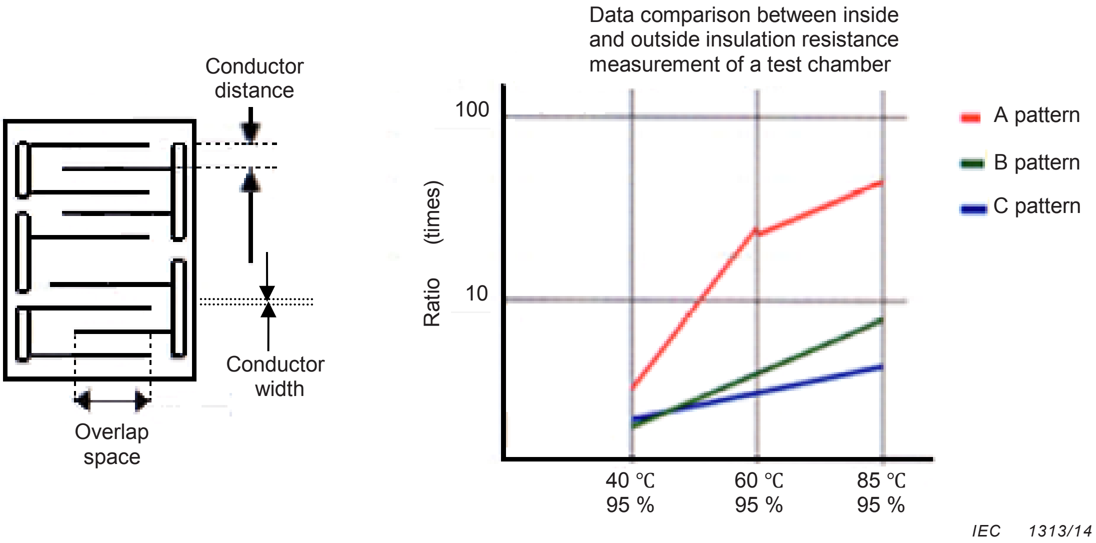


Figure 38 – Relationship insulation resistance with charging time of capacitor mounted boards

2) The difference between inside and outside insulation resistance measurement value of a test chamber are different more than up to 50 times (severe data when measured in a chamber) as shown in Figure 39.



	A pattern	B pattern	C pattern
Conductor width	0,165 mm	0,318 mm	0,635 mm
Conductor distance	0,165 mm	0,318 mm	0,635 mm
Overlap space	15,75 mm	15,75 mm	15,75 mm

Figure 39 – Comparison of insulation resistance measurement inside and outside a test chamber

3) Relationship between relative humidity and insulation resistance

Insulation resistance when measured outside a test chamber may differ significantly depending on the measuring temperature and humidity. Insulation resistance measured for the exposed conductor pattern on a board can vary by two orders of magnitude as shown in Figure 40. IEC 60068-1 specifies the measuring environment as the standard atmospheric condition (15 °C to 35 °C and 25 % to 75 %RH), but the measured value may deviate considerably in these environments.

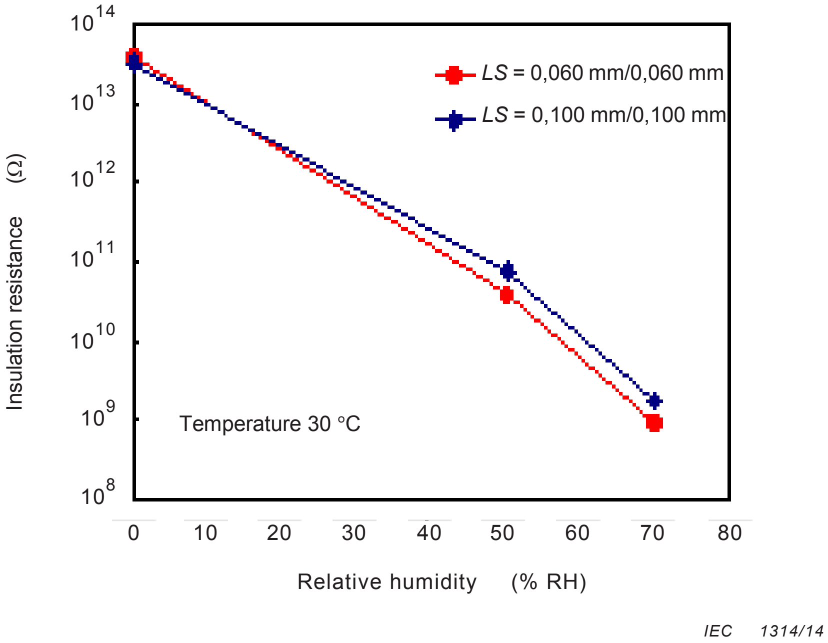
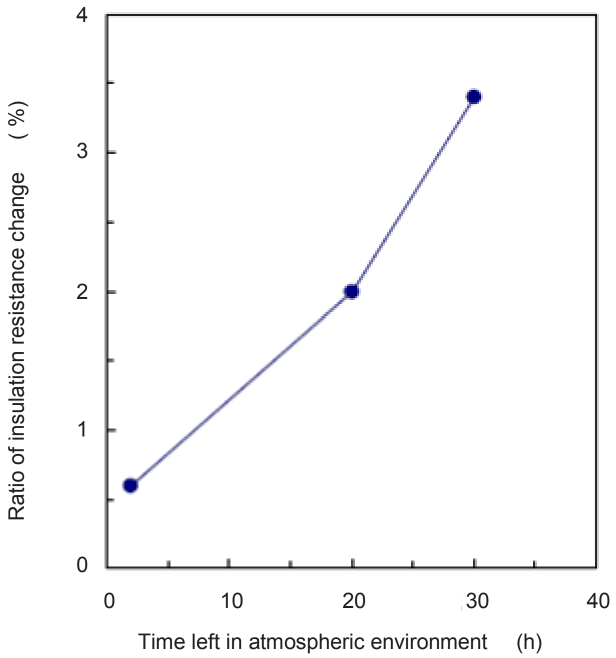


Figure 40 – Relative humidity and insulation resistance

4) Effect of the time a specimen is kept outside a chamber on the insulation resistance

Care should be taken when a specimen is taken out of a chamber and is returned to the chamber for some reason. The resistance measurement when taking out a specimen of a chamber reflects the sample status changes from wet to dry and again back to wet state. Care about the dry condition of the specimen at the time of the insulation resistance measurement.

In most standards, measurement is required to be made within 48 h from the time the specimen is taken out of a chamber and returned back to the chamber within 96 h. There is a tendency for the insulation resistance to increase with time as the specimen is taken out as shown in Figure 41. It is not appropriate to leave a specimen for a long time outside a chamber. JPCA ET 01 specifies the time to take a specimen out of a chamber to be less than 5 % of the total test time.



IEC 1315/14

Figure 41 – Effect of interruption of measurement on insulation resistance (variation of insulation resistance with the time left in atmospheric environment)

5.2 Measurement of dielectric characteristics

5.2.1 General

The rresent trend in the evaluation of reliability in humid environments is the measurement of the dielectric characteristics under environmental stress. Electrical characteristics are basically evaluated by insulation resistance. The evaluation of dielectric characteristics is getting more significance as electronic products today are handling very high frequency and high speed signal processing. It is necessary to consider the dielectric characteristics rather than simply the insulation resistance.

5.2.2 Dielectric characteristics of board surface

Positive charges in the material deviate their position toward the electric field vector and the negative charges toward to the opposite direction when a DC voltage is applied to a dielectric material. This effect is called dielectric polarization. There are various types of polarization such as electron polarization, ionic polarization, directional polarization and boundary polarization. A type of polarization is selected for a material by constructing elements of the material. Rotation of dipoles occurs when an AC voltage with an angular frequency of ω is applied to such a material. The delay for such a rotation of dipoles occurs as the frequency increases. The electric field flux D then lags to the electric field E with an angle δ. E and D are expressed by the following equations:

$$E = E_0{}^{j\omega t} \tag{1}$$

$$D = D_0{}^{j(\omega t - \delta)} \tag{2}$$

The dielectric constant (complex) ε becomes $D = \varepsilon E$,

$$\begin{aligned} \varepsilon &= D/E = D_0{}^{j(\omega t-\delta)} \big/ E_0{}^{j\omega t} \\ &= D_0 \big/ E_0{}^{(-j\delta)} = D_0/E_0(\cos\delta - j\sin\delta) = \varepsilon' - j\varepsilon'' \end{aligned} \tag{3}$$

A relation $\tan\delta = \varepsilon''/\varepsilon'$ is obtained from Equation (3). This tan δ is called the dielectric tangent.

The energy consumed in a unit volume of dielectrics under an AC electric field power consumption density, W, can be calculated by the following Equation (6).

The current density I flowing in the dielectrics is:

$$I = dD/dt = j\omega D = j\omega\varepsilon E = j\omega\varepsilon' E + \omega\varepsilon'' E \tag{4}$$

The power consumption density W is then

$$W = EI\cos\theta = \omega E^2\varepsilon'' \tag{5}$$

$$W = \omega E^2\varepsilon'\tan\delta \tag{6}$$

where θ is the phase difference between E and I.

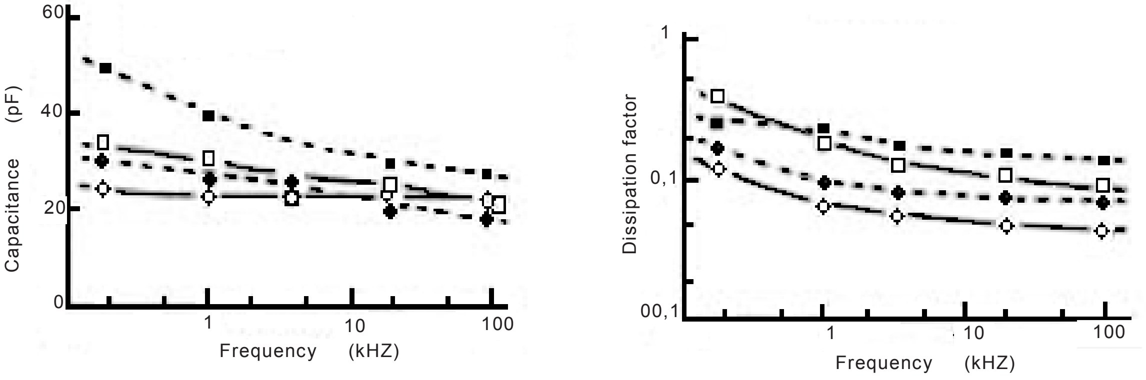
tan δ is used as an indication of energy loss in a dielectrics. The frequency range in which this energy loss is observed depends on the type of polarization of the material. The larger the dipole moment, the slower it will follow the changes of the electric field. The dielectric dispersion appears at a low frequency range. The change of the dielectric constant with the frequency is called dielectric dispersion.

5.2.3 Migration and dielectric characteristics of the printed wiring board surface

There are some studies which show that the dielectric constant (static capacity) and tan δ increase as migration proceeds; conversely, migration can be evaluated from the increase of the dielectric constant and tan δ. Some examples of such studies are given below.

1) Dielectric characteristics and migration on the surface of a board

   The first example is the case of a board made of a polyimide film and an adhesive layer. A comparison is made of the characteristics of un-degraded and degraded specimens treated in a high temperature and high humidity environment with an applied voltage. Figure 42 shows the frequency response and Figure 43 the temperature response. It is shown that both static capacitance and DF (dissipation factor, equivalent to tan δ) are increased. Measurement is made with a board so that an abnormal change may be detected if the local static capacitance and DF increases caused by migration are significant compared to the increases of the board itself. The characteristics of the board change with time especially at an environment of high temperature and high humidity. The characteristics of the adhesive film are improved at the early stage of the experiment and then degrade as time passes. It is necessary to isolate the degradation caused by migration.



IEC 1316/14

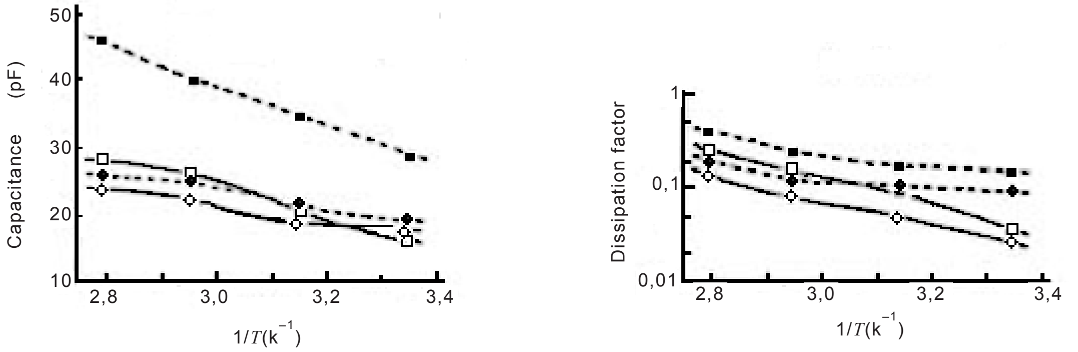
IEC 1317/14

Sample: polyimide system film

Degradation condition: 85 °C, 85 %RH, 50 V, 1 000 h
Measurement condition: 65 °C, 85 %RH

Sample	Symbol		Conductor distance (mm)
	Normal	Degradation	
A	○	●	2
C	□	■	2

Figure 42 – Frequency response of dielectric characteristics of printed wiring board



IEC 1318/14

IEC 1319/14

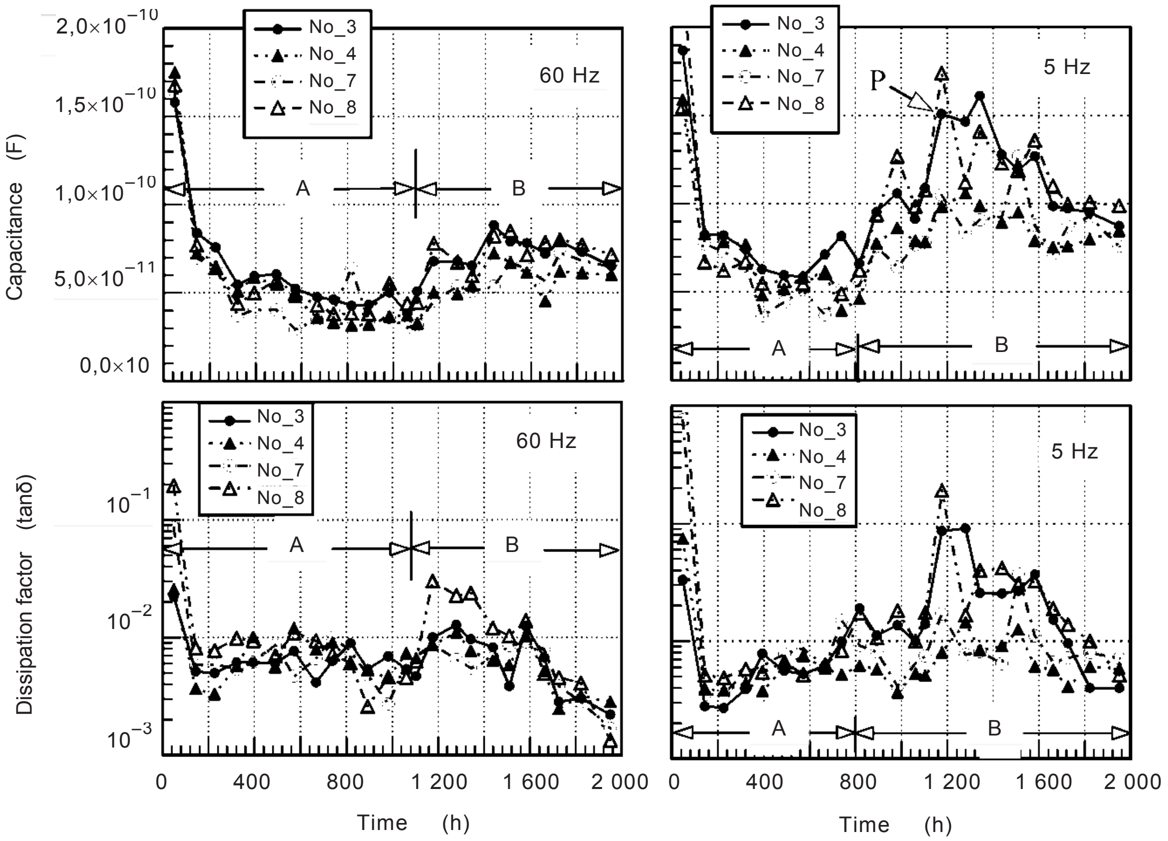
Sample: polyimide system film

Degradation condition:85 °C, 85 %RH, 50 V 1 000 h
Measurement condition: 85 %RH, 1 MHz

Sample	Symbol		Conductor distance (mm)
	Normal	Degradation	
A	○	●	2
C	□	■	2

Figure 43 – Temperature response of dielectric characteristics of printed wiring board

The other example is for the measurement of a glass-fiber reinforced epoxy board as shown in Figure 44. Degradation of the board in this case is not significant and the change due to migration is not significant either. Detection sensitivity in this case at high frequency is not very high but there is better detection sensitivity at a very low frequency of 5 Hz. This shows that the variation of the dielectric characteristics caused by migration is relevant to ion mobility in the board and gives better detection sensitivity. It should be noted that an increase of dielectric characteristics is accompanied with migration and that sensitivity is better at very low frequencies. It should also be noted that the characteristics of the board themselves may vary with the treatment in a chamber in a high temperature-high humidity environment in understanding the effect of migration in such a test.

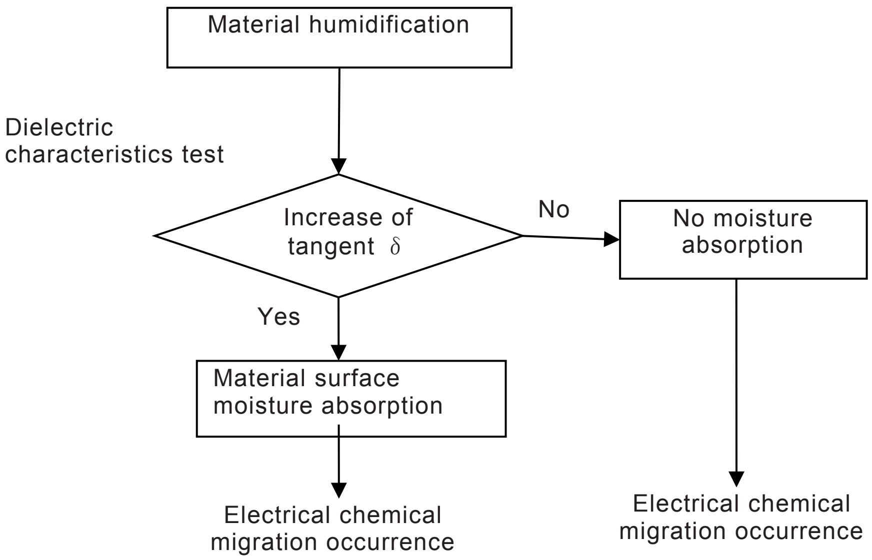


IEC 1320/14

Figure 44 – Changes of static capacitance and tan δ of a specimen through a deterioration test

2) Application of dielectric characteristics measurement to flux evaluation

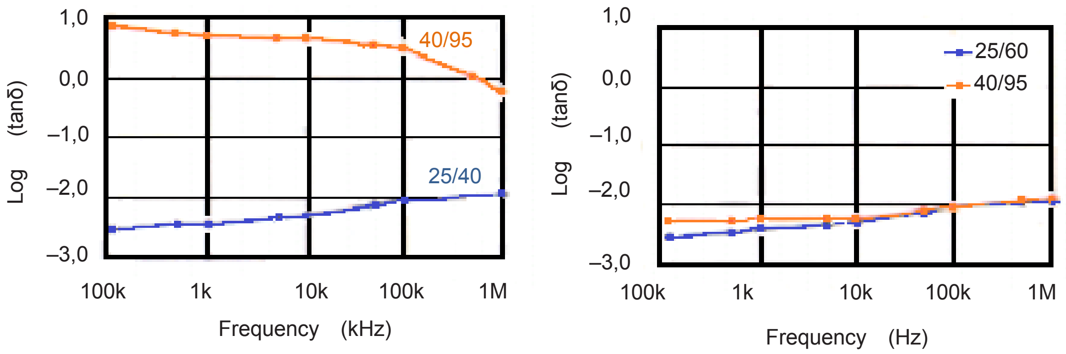
The soldering flux used in electronic equipment is basically resin, such as rosin, added with an activator such as halide acid salt of amine. It is a complex dispersion system of a mixture of two substances with different conductance and dielectric constants. There are countless interfaces of different materials, so the surface polarization in flux and its residue on the surface of a board can be detected. Water in the air is absorbed into a flux residue on the surface of a board if there is a substance with high water absorbability such as an ionic substance in the residue, and surface polarization occurs. It is possible to evaluate reliability changes due to flux using this method. Figure 45 shows a procedure to detect migration using the dielectric characteristics test.



IEC 1321/14

Figure 45 – Test procedure of a dielectric characteristics test

Figure 46 shows test results of two fluxes, one with a component of high water absorbability and the other of low water absorbability. A significant difference is observed in the dielectric tangent before and after water absorption. Migration was observed at a rather early time in an insulation resistance test for a specimen using a flux of high water absorbability.



IEC 1322/14 IEC 1323/14

a) tangent δ of flux A **b) tangent δ of flux B**

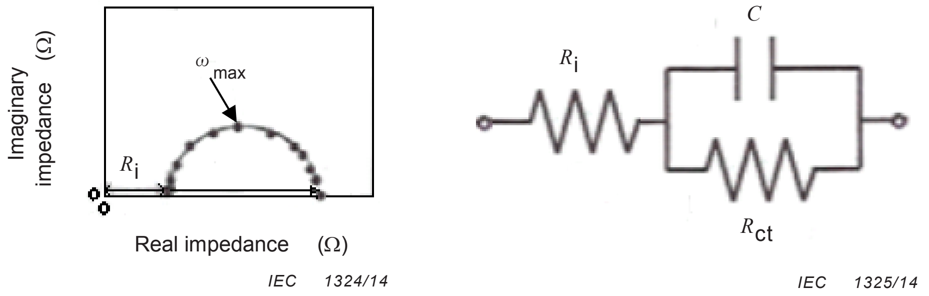
Figure 46 – Comparison of dielectric characteristics of two types of flux

5.2.4 Evaluation of migration by AC impedance measurement

The AC impedance method is often used in electrochemistry. It is a method to study an interface and to observe reactions from a phase difference observed when a very small AC signal is applied to a specimen. R_i in an electrochemical reaction is the ion resistance to movement, R_ct is the electric charge resistance, and C is the capacitance of the electric double layer (interface capacitance) as illustrated in Figure 47. These values are available from the Cole-Cole plots at different frequencies. Distance on the horizontal axis from the origin to the start of the semi-circular curve is R_i, and the diameter of the semi-circle is R_ct. C is the inverse of the angular frequency at the top of the semi-circle (ω_max) times R_ct:

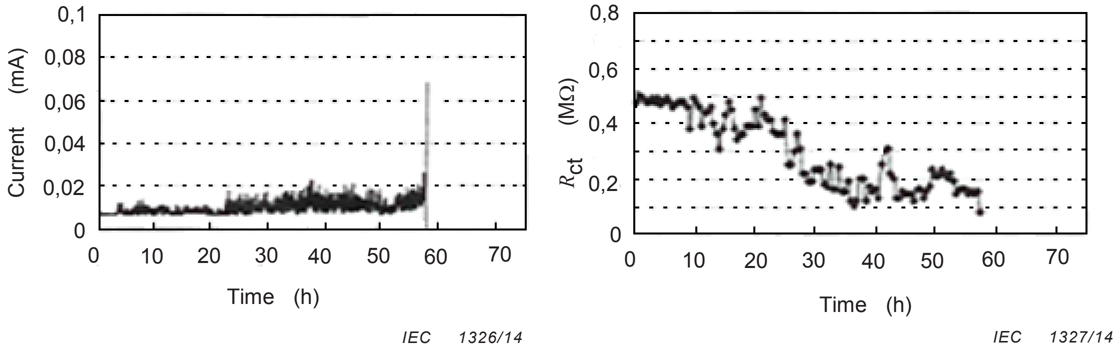
$$C = \frac{1}{\omega_{\max} \cdot R_{\mathrm{ct}}}$$

Figure 48 shows the correlation of the generation process of the migration observed and the time variation of a Cole-Cole plot. This is an example of the progression of migration as the change with time of R_{ct} in an IC flip-chip module made of anisotropic conductive film (ACF). Observation was made of a specimen kept in an environment of 85 °C, 85 %RH with an applied voltage of 75 V DC added with an AC signal (10 kHz to 1 Hz) of an amplitude of 0,35 V. Figure 48 shows the time dependence of R_{ct} obtained from the Cole-Cole plot. The leakage current increased and R_{ct} decreased as migration progressed in the specimen.



a) Cole-Cole plot b) Equivalent circuit of plot a)

Figure 47 – Measurement principle of EIS (Electrical Insulation System)



a) Current b) R_{ct}

Figure 48 – Gold (Au) plating, non-cleaning

6 Evaluation of failures and analysis

6.1 Criteria for failures

Migration is evaluated by measuring the leakage current or insulation resistance. A test is conducted until the insulation resistance decreases to a specified level and the time to reach that level is taken as the failure time. Table 17 gives the insulation resistance values regarded as failures specified by available standards.

The measurement of insulation resistance on its own cannot elucidate the state of failure or migration. It is necessary to study specimens to identify the region of migration and analyze the specific region using the techniques described in 6.3. The decrease of insulation resistance often recovers to a higher value but the decrease that once happens to a specimen means the specimen is in failure state. When a short circuit is formed by a dendrite growth or CAF, the insulation resistance returns to a state that is not a failure because the dendrite or CAF disappears under the effect of the short-circuit current.

Table 17 – Criteria of migration failure by insulation resistance

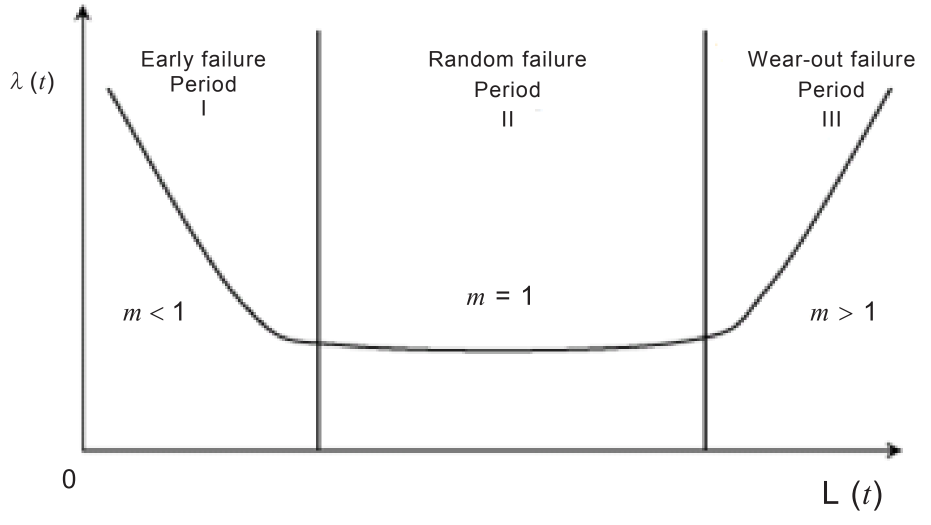
Group	Standard no.	Criteria
JPCA	ET-01	Measurement inside of chamber: $< 1 \times 10^6\ \Omega$ Measurement outside of chamber: $< 1 \times 10^7\ \Omega$
IPC	6012	Class 1: Equipment in operation (no specified value) Class 2: $< 1 \times 10^8\ \Omega$ Class 3: $< 5 \times 10^8\ \Omega$

6.2 Data analysis

6.2.1 Analysis of experimental data

1) Evaluation of life

It is convenient to analyze the failure data obtained from measurement to plot on a Weibull probability distribution chart to estimate the life of the printed wiring board or of the equipment. It is desirable to have the number of specimens, n, to be more than 10. It is well known that the life of a product is expressed by a bathtub curve as illustrated in Figure 49. Failures in printed wiring boards caused by migration may be classified as the early failure period caused in the production process or due to some material defects and structures of the board. The random failure mode follows with a rather low constant failure rate, and lastly there is the wear-out failure mode. The time-dependent distribution of failures in boards can be expressed by a Weibull distribution and be plotted on a Weibull chart to analyze the failure mechanism and to estimate the failures to appear in the boards. The Weibull distribution function $F(t)$, the reliability function, $R(t)$, and the failure rate function $\lambda(t)$ are expressed by Equations (7), (8) and (10).



IEC 1328/14

Figure 49 – Bath tub curve

m is the shape parameter; $m < 1$ is for the early failure period; $m = 1$ is for the random failure period and $m > 1$ is for the wear-out failure period. η is the scale parameter and is the time to failure of 63 %. In the case where $m = 1$, η is the MTTF (mean time to failure). γ is the position parameter and no failure occurs to this point.

The Weibull probability chart is a chart in graphic form of the equation (10) which is converted into equation (14). It is recommended to use the horizontal axis for the time parameter and the vertical axis to plot in a median rank of failures in an approximation expressed as (i-0,3)/(n+0,4) in presenting experimental data on a Weibull chart. Here n is the number of specimens and i is the accumulated failures. The shape parameter (m) is obtained from the approximated linear line of the plot. An expected life time, or an averaged life time is then obtained.

2) Data processing of specimens with interrupted experiment

The Weibull type accumulation hazard plotting is often used for data analysis of a test in which a test is continued while another test is interrupted. This procedure can be applied to a case where there are more than one failure modes. One specific failure mode is handled as a failure mode in the study and other failures caused by other modes are treated as the data of an interrupted test. The accumulated hazard function $H(t)$ is expressed by equation (14) in terms of the Weibull distribution function $F(t)$. It is possible to obtain the shape parameter m by taking the natural logarithm for both of the axes. It is recommended to use the combined Weibull probability and accumulated hazard chart, a chart which can be used for both the Weibull probability and also the accumulated hazard for the analysis of the incomplete set of experimental data.

The Weibull distribution function $F(t)$ is expressed as

$$F(t) = 1 - \exp\left\{-\left(\frac{t-\gamma}{\eta}\right)^m\right\} \tag{7}$$

$$R(t) = \exp\left\{-\left(\frac{t-\gamma}{\eta}\right)^m\right\} \tag{8}$$

The failure rate function $\lambda(t)$ is

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{1}{R(t)} \bullet \frac{d(1-R(t))}{dt} = -\frac{1}{R(t)}\frac{dR(t)}{dt} \tag{9}$$

and

$$\lambda(t) = \frac{m}{\eta^m}(t-\gamma)^{m-1} \tag{10}$$

When m = 1

$$\lambda(t) = \frac{1}{\eta} \tag{11}$$

η = MTTF（or MTBF）has an exponential distribution.

Let γ = 0 in equation (7), then:

$$F(t) = 1 - \exp\left\{-\left(\frac{t}{\eta}\right)^m\right\} \tag{12}$$

and

$$1 - F(t) = \exp\left\{-\left(\frac{t}{\eta}\right)^m\right\} \tag{13}$$

Take the logarithm of both sides of the equation twice. It becomes

$$\ln\left[\ln\{1/(1-F(t))\}\right] = m\{\ln t - \ln \eta\} \tag{14}$$

The Weibull probability chart is the graphical expression of the equation. The accumulated hazard function $H(t)$ is expressed with (γ = 0) as equation (14) from the Weibull distribution function.

The Weibull distribution function is

$$F(t) = 1 - \exp\left\{-\left(\frac{t-\gamma}{\eta}\right)^m\right\}$$

The accumulated hazard function $H(t)$ is then

$$H(t) = \left(\frac{t}{\eta}\right)^m \tag{15}$$

We obtain $\ln H(t) = m(\ln t - \ln \eta)$ by taking the logarithm of both sides of the equation. Taking the vertical axis for $\ln H(t)$ and the horizontal axis for $\ln t$, the Weibull type accumulated hazard chart is obtained.

3) Remarks
   a) Remarks on plotting experimental data to the Weibull probability chart
      i) The size of a plot on the chart should be larger than the width of the regression line to be drawn on the chart (approximate diameter of 1 mm).
      ii) The regression line should be drawn observing the entire plotting points.
      iii) The regression line should be drawn especially to cover the points distributed in the range from 10 % to 90 %.
   b) Reading a Weibull probability chart

      The failure mechanism should be the same for all the specimens and follow the Weibull distribution if a linear regression line is obtained. There are cases where a linear regression line is obtained in the Weibull plotting even if plural failure mechanisms exist in the specimens. Plotting on an accumulated hazard chart is useful in analyzing such failure mechanisms. There are cases where the failure mode in specimens is the same but failure mechanisms are different. The chart often shows in such cases a regression line with a bend. Failures developed within a range with a small accumulated failure probability, $F(t)$, may generate a significant number of failures in the future. It is very important to make a careful analysis of the failure mode to find the possible origins of failures.

6.2.2 Relationship of the parameters in the experimental data and an example of the analysis

Figure 50 shows an example of experimental data of water absorption and insulation degradation in a HAST of components made of an insulating material. It is possible to confirm the relationship between the time needed for weight loss and the time required for insulation resistance degradation by overlapping the data of the weight decrease (change of water absorbability) with the variation data of insulation resistance. This is a case where the change of insulation resistance is caused by the variation of the material characteristics themselves. It is a very useful method to analyze the sources of parameter changes in a material.

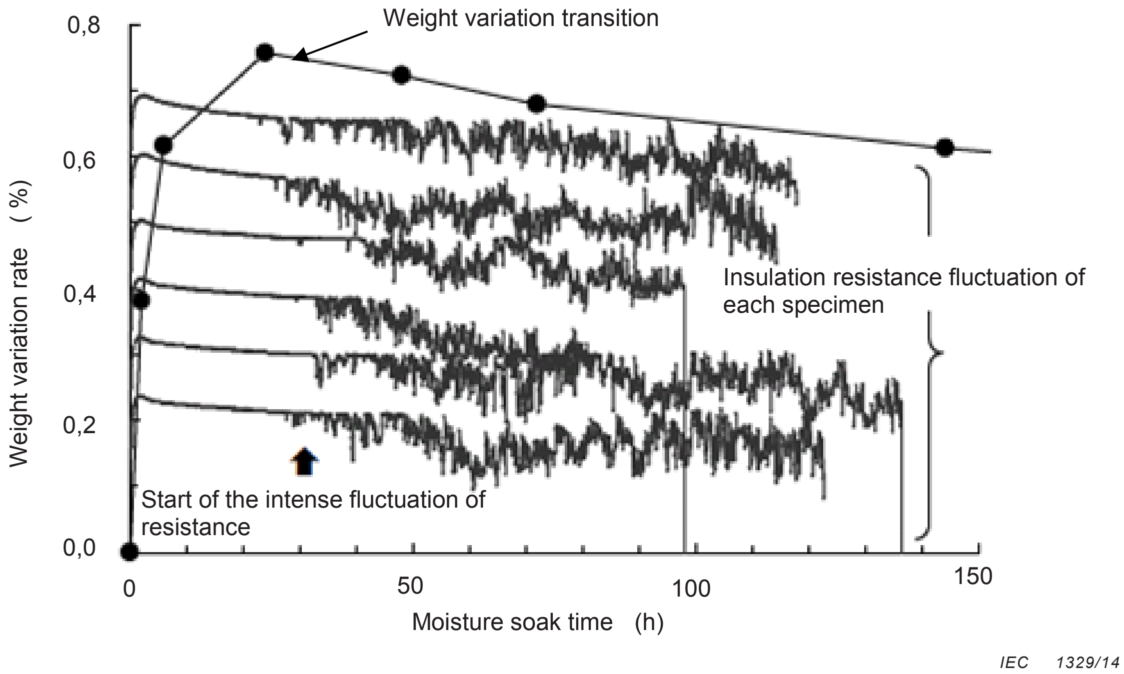


Figure 50 – Relation between the variation of insulation resistance and the weight changes by water absorption

6.2.3 Electric field strength distribution

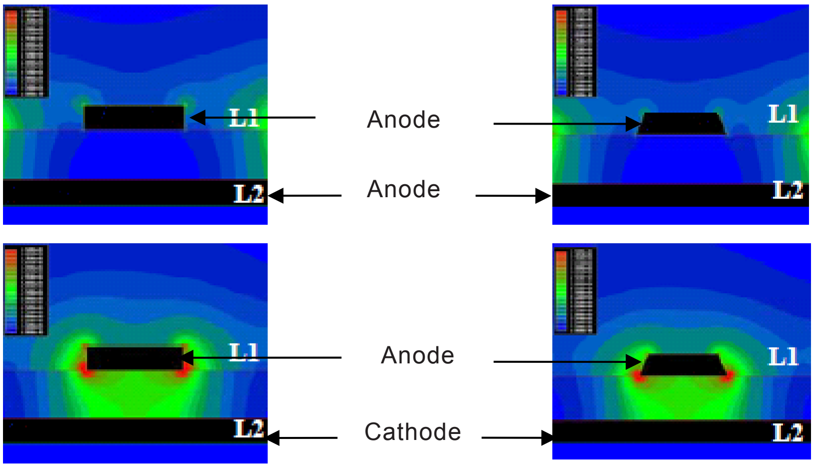
A limited element analysis of the electric field strength near a conductor pattern is useful for the analysis of experimental data. Below are some examples of such analyses.

1) Effect of the underlying conductor pattern in a multi-layer board

   This is the case of an electric field analysis of electric field distribution around an anode conductor pattern when an electric voltage of 50 V DC is applied to a multi-layer board with an underlying conductor pattern (plane) and an infinitely spreading surface conductor pattern (line spacing of 0,080 mm) with an insulating layer in between. The analysis shows the electric field is concentrated as observed at the lower edges of the conductor pattern (line) in a cross section of a line. There is a tendency for an electric field to be slightly stronger for a conductor with a cross-section in a rectangular shape compared to a conductor with a cross-section in a trapezoid shape. The electric field strength around the conductor pattern in the top layer is affected by the electric field of the conductor in the lower layer.

2) The potential and electric field strength of a pair of parallel conductors

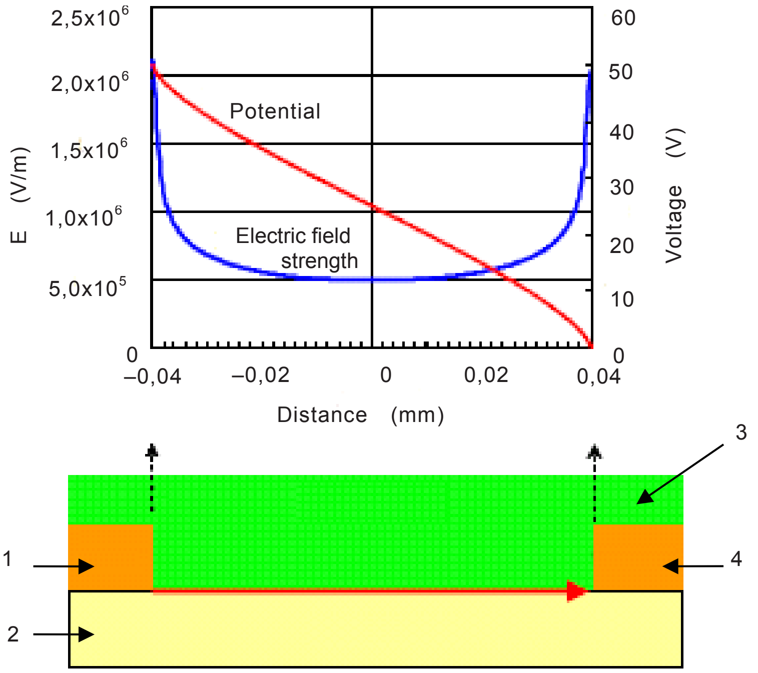
   Figure 51 and Figure 52 show the potential distribution and electric field strength of a pair of parallel conductors of an infinite length with a spacing of 0,08 mm on an insulating resin layer with an applied voltage of 50 V DC between the conductors, and the case of a conductor pattern formed on an insulating layer and covered with solder resist. The potential at the edge of a conductor which is connected to a positive voltage (anode) is high and almost decreases according to movement distance from the anode to the cathode. The electric field strength is slightly higher at the anode edge than at the cathode edge, and is nearly constant in the area ± 25 % from the centre.



IEC 1330/14

a) The line form is a rectangle　　b) The line form is a trapezium

Figure 51 – Distribution of electric field between line and plane



IEC 1331/14

Key

1 Anode
2 Base material
3 Solder resist
4 Cathode

Figure 52 – Distribution of the electric field between lines

6.3 Analysis of specimen with a failure, methods of analysis and case study

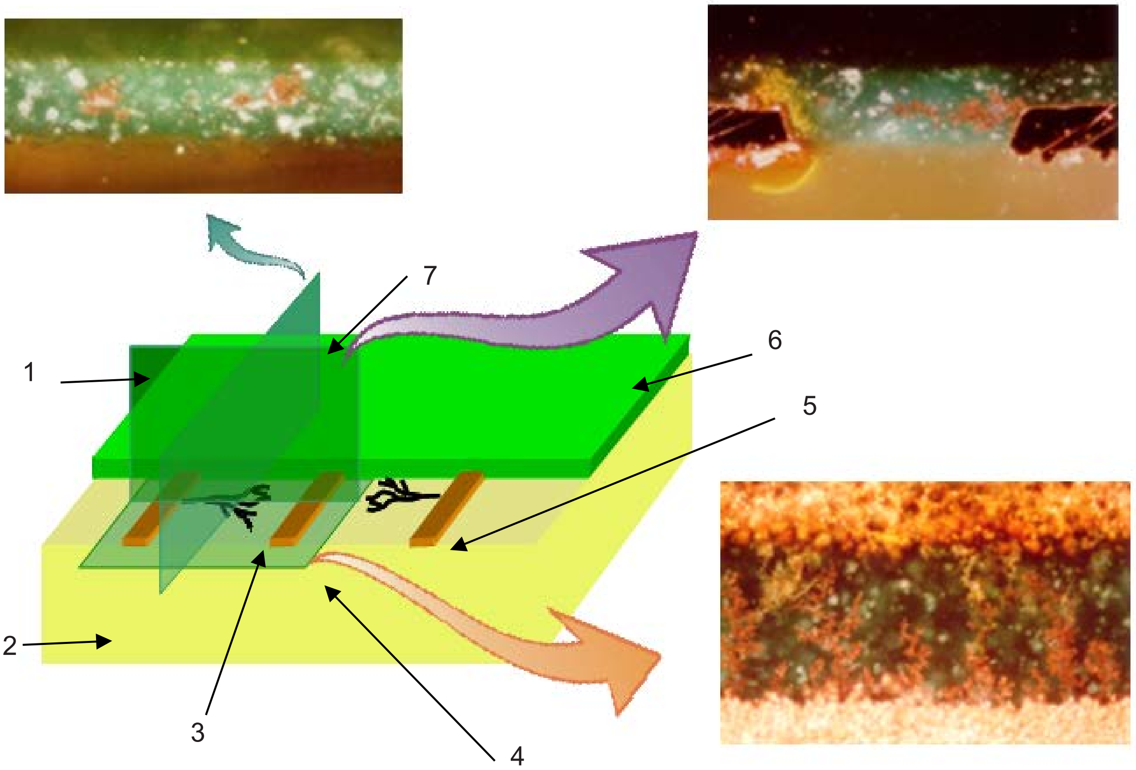
6.3.1 General

The analysis technique of a specimen with a failure caused by migration depends on the structure and position of the failure in the specimen. Failures in an inner layer may be observed at the cross section revealed by the lapping of a specimen buried in resin. The thin film like solder resist may be observed by diagonal cutting method that there are more analysis points than the cross-section observation.

6.3.2 Cross section

1) Specimen preparation

The region with a failure is cross cut using a cutting instrument such as a diamond saw. Care should be taken not to impose stress to a failure itself of bend or vibration. The cutting face should be confirmed by deciding from which side the failure is to be observed. The failure analysis may differ considerably by the cutting position as shown in Figure 53.



IEC 1332/14

Key

1	Direction A
2	Base material
3	Electrochemical migration
4	Direction C
5	Electrode
6	Solder resist
7	Direction B

Figure 53 – Different observations of the same dendrite according to different cross section cutting planes

2) Burying of a specimen

A piece of specimen to be observed is placed with the face to be observed downward in a resin filled in an appropriate container coated with a release agent. Use a jig to fix the specimen so that it does not tilt while the resin is hardened. The resin to be used may be selected from epoxy, acryl, or polyester resin depending on the proper curing temperature, curing time, compression during cure, fluidity, and hardness. Epoxy resin which cures at room temperature is often used. In the case of a specimen with a minute air gap, vacuum impregnation equipment may be used to closely adhere to the resin or to remove the air bubble in the resin.

3) Cutting

A specimen buried and cured in resin block is cut close to the specimen. The lapping time is different by the cutting position.

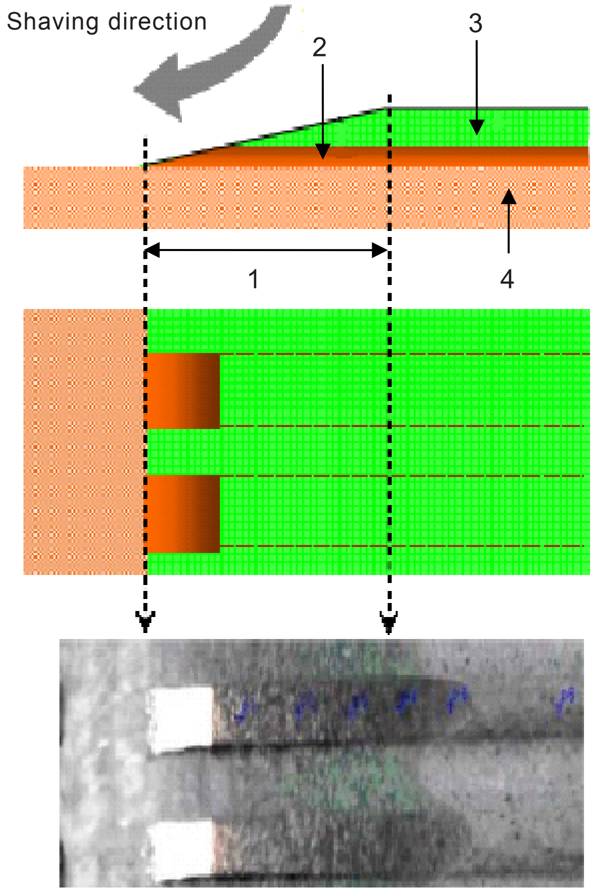
4) Lapping

A specimen is usually a mixture of hard and soft materials. It is difficult to lap a specimen with the same lapping condition. It is necessary to select a proper abrasive and lapping condition according to the property of the lapped surface and the object of analysis. Lapping may be divided into three steps, the first step is to expose the face to be observed, the second step is intermediate lapping and the third is the final lapping to reveal the clear surface of a specimen for analysis. The first lapping may be made using water resistant sandpaper (300 grit ≈ 85 µm). The second step is made using an abrasive buff with a diamond powder of several micrometers. The final lapping removes scratches produced by lapping with an abrasive buff and aluminium oxide powder of grain size of about 0,05 µm.

5) Cleaning and drying

The lapped specimen should be cleaned under running water using a neutral detergent. The specimen should be dried quickly under a strong air flow using an air gun to prevent stain or erosion at the specimen surface.

Analysis of a specimen in the depth direction of a thin material such as solder resist is to be made before on a cross section formed by the vertical lapping of a specimen. It was possible to analyze only one or two points by infrared spectrophotometry (ATR, attenuated total reflectance) in the depth direction. Now it is possible to analyze more than five points by angle lapping of a specimen as illustrated in Figure 54. ATR analysis of an angle lapped specimen of solder resist at 5 points inside the film and a point on the surface revealed by infrared microspectroscopy (micro ATR) showed that the film right above the copper conductor and the top surface of the film had different structures as shown in Figure 55.

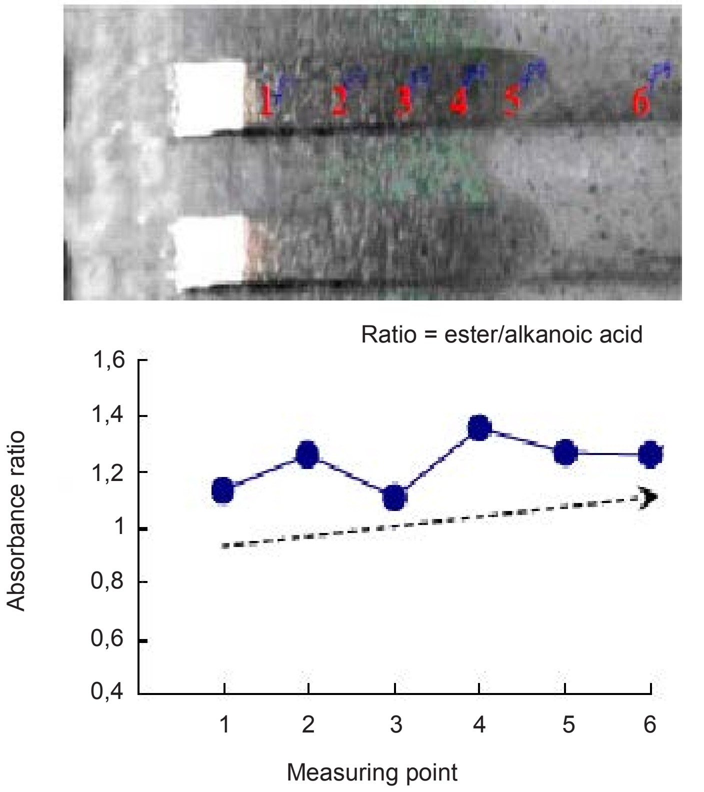


IEC 1333/14

Key

1 Shaving area
2 Line
3 Solder resist
4 Base material

Figure 54 – An example of angle lapping



IEC 1334/14

Figure 55 – Structure analysis of an angle lapped solder resist in the depth direction

6.3.3 Optical observation

Table 18 shows the methods used in the optical observation of the specimens.

Table 18 – Various methods for optical observation of failures

Observation method	Principle	Intended purpose	Detection limit
1. Stereo microscope	An optical microscope, which uses the visible wavelength of light and focuses the light with a refractive lens. A three-dimensional image can be recognized by viewing the object in both eyes.	Three-dimensional observation at low magnification.	Magnifying power: x4 to x100
2. Digital microscope	An optical microscope, which captures images with a camera and displays the object as a digitized image. A CCD (charge coupled device) camera is commonly used, and various functions can be integrated, such as an endoscope.	Defect detection of materials and parts at low to high magnification.	Magnifying power: x5 to x4 000
3. Metallographic microscope	An optical microscope, which illuminates the specimen from the surface, and is suitable for opaque materials such as metals. Both reflection and transmission observations are possible.	Defect detection of materials and parts at low to high magnification.	Magnifying power: x5 to x4 000
4. Polarising microscope	An optical microscope with a polarizer, which illuminates with a plane polarized light and where the rotation of the light can be analyzed. It is suitable for the observation of birefringence materials such as crystals and strained non-crystalline substances.	Characterization of polarized materials, crystals and composites.	Resolution: To the order of 1 µm
5. Laser microscope	An optical microscope whose light source is a laser beam. The laser beam scans the surface of the specimen with an AO (acoustic-optic) polarizer and a galvano-mirror. The reflected light from the specimen is captured by a CCD image sensor.	Three-dimensional image of the surface of a specimen, surface roughness analysis.	Resolution: To the order of 0,3 µm
6. Scanning electron microscope (SEM)	An electron microscope that provides the image of a secondary electron intensity emitted from the surface of the specimen. The image can be obtained by synchronizing the electron beam and the display equipment.	Surface analysis, including shape, surface roughness and composition.	Resolution: To the order of 0,3 µm to 0,7 µm

Observation method	Principle	Intended purpose	Detection limit
7. Transmission electron microscope (TEM)	An electron microscope that forms an image of the penetrated electrons with an electromagnetic lens by irradiating the accelerated electron beam to a specimen.	Elemental analysis characterization of crystal structure, substance identification.	Resolution: < 300 nm
8. Scanning probe microscope (SPM)	A group of microscopes that obtains an image of the surface using a probe that scans the specimen (f. ex. A scanning tunneling microscope). The relative position of the probe is controlled based on the force or potential between the probe and the specimen. Mapping images of surface structure, the values of physical properties can be obtained.	Microscopic surface observation, including surface roughness.	1 nm to 10 nm
9.Soft X-ray absorption/emission spectroscopy	X-ray spectroscopy with soft X-ray in ultra vacuum conditions that probes the partial occupied density of the electronic states of a material. X-ray spectroscopy observes the ejected electrons from the outermost atomic layers of the surface, and thus it can identify the elements, quantify the atomic concentrations, determine chemical bonding between elements in the layers. The X-ray absorption spectra are generally obtained by synchrotron radiation that generates tunable X-ray beams.	Non-destructive internal analysis of PCBs, including precipitation of metal components.	Resolution: < 100 nm
10.Atomic force microscope (AFM)	A scanning probe microscope which uses a micro scale cantilever with a sharp probe of which the radius of the curvature is in the nano meter order. The force between the probe and the specimen lead to a deflection of the cantilever. The forces measured in AFM are mechanical contact force, Van der Waals force, capillary force, chemical bonding, electrostatic force, magnetic force, etc.	Atomic level surface observation.	Resolution: Atomic order

6.3.4 Analysis methods

Table 19 shows the typical methods for the analysis of defects.

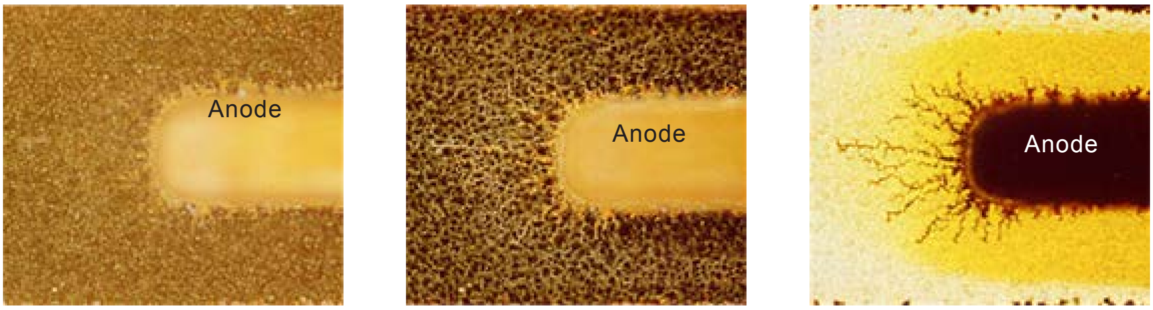
Table 19 – Various methods for defect analysis

Analysis method	Principle	Intended purpose	Measurement limit
1. Electron probe micro analyzer (EPMA)	A micro analysis system that irradiates a specimen with a focused (diameter < 1 micron) electron beam to detect the dispersed wavelength and intensity of a characteristic X-ray generated from the area where the electron beams reach (1 micron to 2 microns), with an X-ray spectrometer.	Qualitative and quantitative analysis of elements of the specimen surface.	Detectable elements: Br to U
2. Auger electron spectroscopy (AES)	A micro analysis system that irradiates the specimen with an electron beam to detect the Auger electron.	Element analysis of thin film below a few nanometers, in the depth direction.	Minimum contents: 0,1 %
3. X-ray photoelectron spectroscopy (XPS,ESCA)	A spectroscopy with X-ray irradiation that detects the kinetic energy of emitted photoelectrons.	Element analysis in the depth direction at a few nanometers below the surface, chemical bonding analysis.	Minimum contents: 0,1 %
4. Fourier transform infrared spectroscopy (FTIR)	A spectroscopy that measures the absorption or reflection of the infrared beam from a specimen. The spectrum is inherent to the independent substance, and it can identify the chemical structure of the unknown substance. The signal captured in the detector is transformed (Fourier transform) in a computer, to provide the infrared spectrum specific to the specimen.	Qualitative analysis of organic substances.	Minimum resolution: several tens of microns
5. Energy-dispersive X-ray spectroscopy (EDX)	One of the X-ray spectroscopies that detects element-inherent X-rays emitted by the specimen due to electron beam irradiation. Quantitative measurement is possible by using standard materials for comparing the intensities.	Qualitative and quantitative micro analysis, area observation, line observation, and mapping images.	Detectable elements: Br to U

6.3.5 Defect observation and analysis

1) Observation of defects with an optical microscope

Figure 56 shows the migration (dendrite) induced for the conductor surface of a printed wiring board which did not have the solder resist coat on it. The observed image obtained by an optical microscope may not be the same due to difference in the illuminating light. The dark field observation can reveal a clearer image of a defect (Figure 56 b)) compared to observation in a bright field (Figure 56 a)) in the case where metal is precipitated on a specimen surface. Observation by transmitted light can give a better image in case there is not an appreciable colour difference and contrast between the precipitated metal and the surface of the board (Figure 56 c)). The light source for the illumination may be selected from a halogen lamp, a xenon lamp, or a mercury lamp depending on the magnification of the observation, the material used, and the thickness of the specimen to be observed.



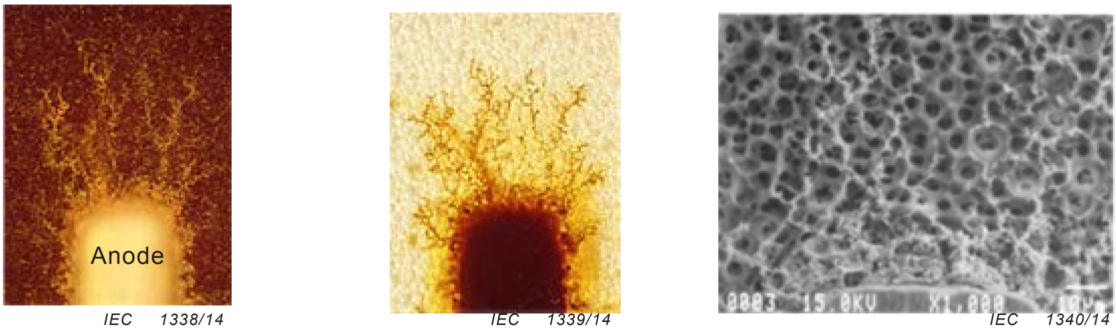
IEC 1335/14 IEC 1336/14 IEC 1337/14

a) Bright field illumination b) Dark field illumination c) Transmission light illumination

Figure 56 – Observed images of dendrite with different illumination methods (without solder resist)

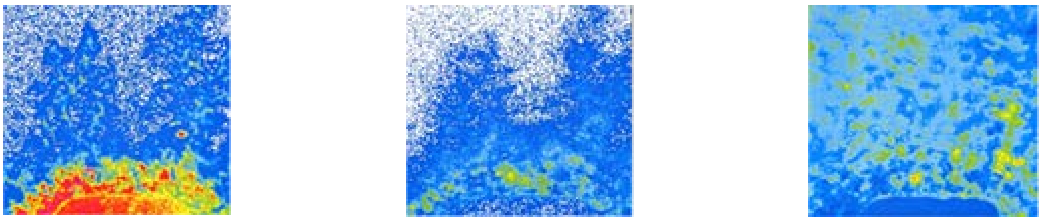
2) Observation of defects with EPMA

Figure 57 shows the migration (dendrite) grown on the surface of a comb type electrode on an FR-4 board without solder resist tested under HAST. Photographs of the element mapping by EPMA of the dendrite induced are shown in Figure 57 d), e) and f). This analysis shows that the dendrite is precipitated at the protruded anchor part of the copper conductor on the surface (in the gap between the copper conductors).



IEC 1338/14 IEC 1339/14 IEC 1340/14

a) Dark field image b) Transmission light image c) SEM image

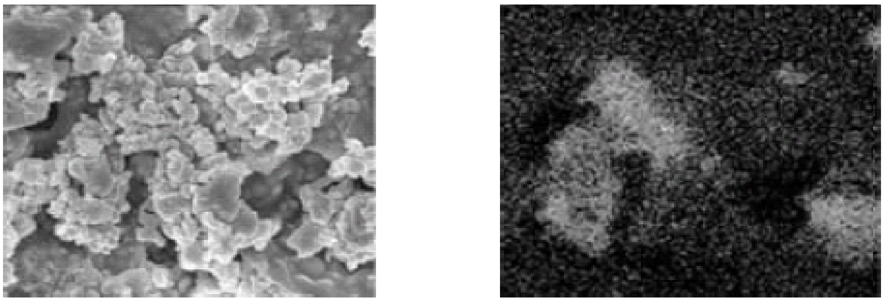


IEC 1341/14 IEC 1342/14 IEC 1343/14

d) Copper e) Chlorine f) Bromine

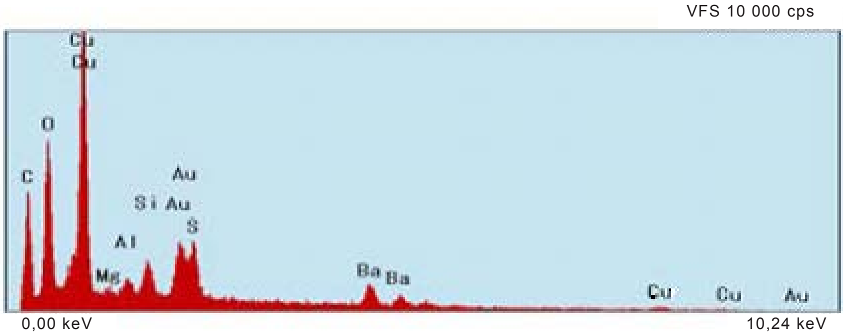
Figure 57 – EPMA analysis of migration (dendrite) on a comb type electrode

Figure 58 shows the region where migration was induced near the conductor under the solder resist of a specimen tested in HAST and the solder resist was removed for observation. The SEM observation shows the precipitation of copper in a swelling state.



IEC 1344/14 IEC 1345/14

a) SEM image b) Mapping image of copper



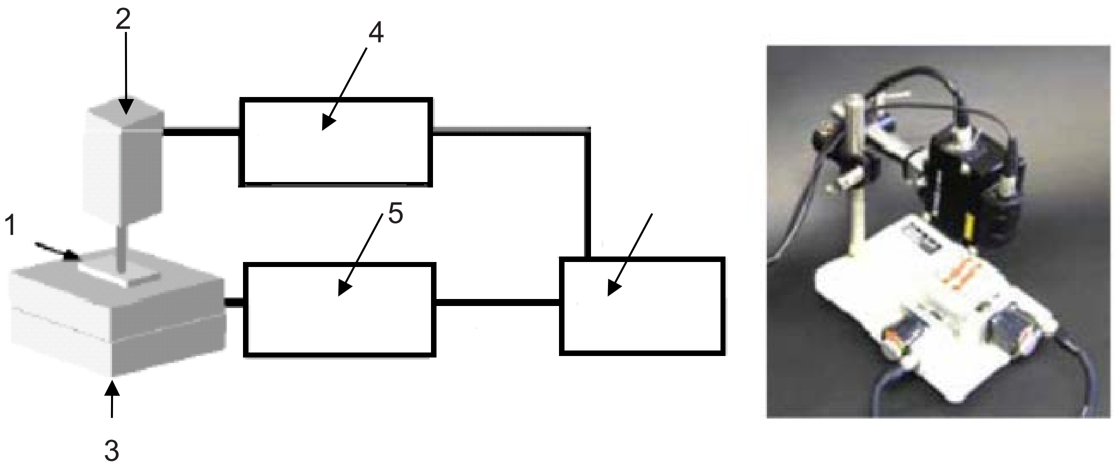
IEC 1346/14

c) Element analysis

Figure 58 – EPMA analysis of migration (dendrite) in the solder resist

3) Observation with AFM (atomic force microscope)

It is difficult to observe the 3D structure of a dendrite with an optical microscope or an electron microscope. Figure 61 shows an automatic measurement of the 3D structure of a dendrite using a 3D measuring system using a displacement meter by means of laser light focusing, as illustrated in Figure 59. Figure 60 shows the electrodes which the dendrite was generated.



IEC 1347/14

Key

1 Sample

2 Laser head

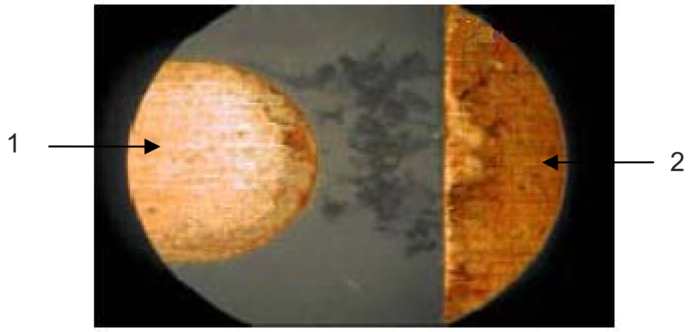
3 X-Y stage

4 Laser focus controller

5 X-Y stage controller

6 Computer

Figure 59 – 3D shape measuring system



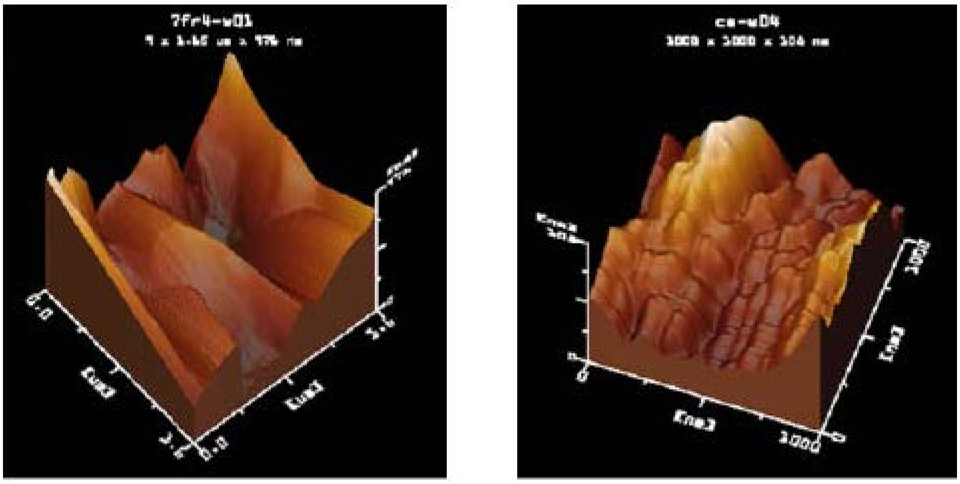
IEC 1348/14

Key

1 Anode

2 Cathode

Figure 60 – Electrodes which migration was generated



a) Anode before dendrite occurrence

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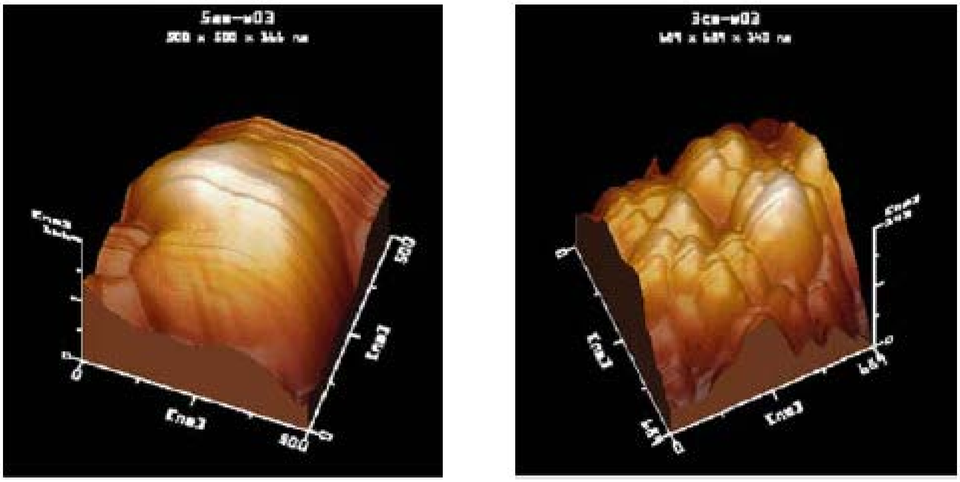
b) Cathode before dendrite occurrence

IEC 1350/14



c) Anode after dendrite occurrence

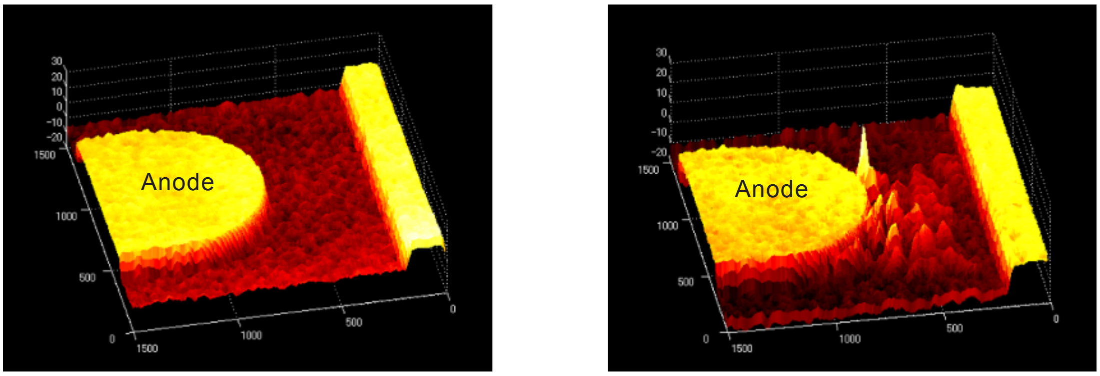
IEC 1351/14

d) Cathode after dendrite occurrence

IEC 1352/14

Figure 61 – 3D observation of electrodes before and after the test

It is possible to make a quantitative analysis of the amount of dissolution and precipitation of a metal electrode by knowing the 3D dimension of the electrodes. This analysis is also important in helping to know the changes of the electric field induced by the generation of a dendrite. Figure 62 shows the 3D observation of a dendrite.



IEC 1353/14 IEC 1354/14

a) Before dendrite generation b) After dendrite generation

Figure 62 – 3D observation of dendrite

6.4 Special remarks on the migration phenomenon after the test

1) Specification of the board and criteria for evaluation

The effects of the arrangement of the conductor electrodes and shape are studied for a board made of glass cloth epoxy resin copper clad laminate and solder resist coated over the conductor with the structure shown in Table 20 tested under HAST with the conditions given in the table.

Table 20 – Board specification and test conditions

Items	Contents
Glass cloth epoxy resin copper clad laminate	FR-4/T_g 120 °C to 130 °C (TMA method)
Solder mask	Low T_g type/ T_g:110 °C to 130 °C (TMA method)
Conductive pattern length	0,018 mm
Space between conductors	0,080 mm
Test conditions	HAST:130 °C,85 %RH,50 V/DC

2) Arrangement of conductor pattern and its shape

The effects of the arrangement of conductors and the shapes of the tip of a conductor for the following three cases were studied:

a) The effect of the amount of overlap of the rectangular conductor pattern given in Table 21.

b) The effect of the ratio of the area of two facing rectangular conductor patterns given in Table 22.

c) The effect of the shape of the end points of the conductor patterns shown in Table 23.

3) Evaluation

a) Effect of the overlap length of the conductor pattern (see Table 21)

The time to failure was short for the conductor pattern with a larger overlap. There was no significant difference in the short circuit mode between the end part of the conductor and the main body of the conductor itself.

b) Effect of the ratio of the areas of two facing rectangular conductor patterns (see Table 22)

There was a trend that the time to failure was short for a conductor pattern with a larger width. No significant difference in the short circuit mode was found. The current concentration at a narrower conductor could explain the test result.

c) Effect of the shape of the end points of conductor patterns (see Table 23)

The time to failure is roughly in the order of the tip shape of the facing electrode of the conductor (round, flat, edged) for the flat end of a conductor. The time to failure for a pair of conductors of the same shape is roughly, i.e. the difference in the shape of the corner of the conductor: edged, flat, round. The area of the gap between electrodes, for example of the electric field concentration, may explain the difference.

The shapes of electrodes and their arrangement can affect the time to failure. Care should be taken in deciding the electrode design.

Table 21 – Effect of the overlap of electrodes

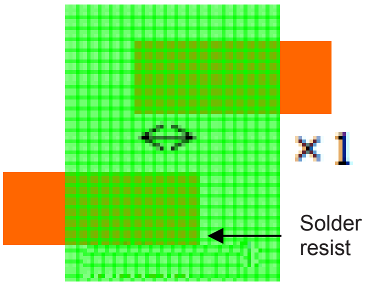
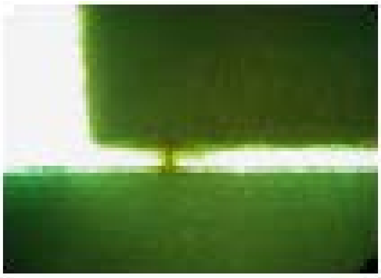
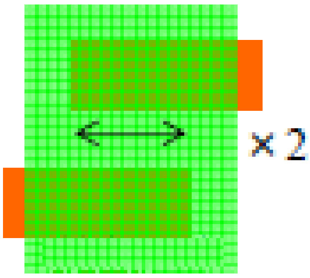
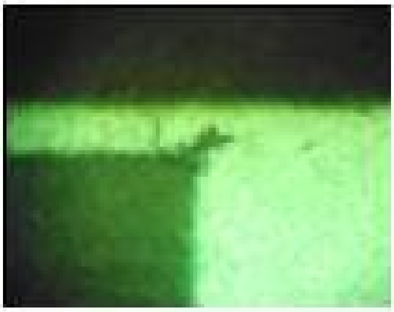
Position and form	MTTF (h)	Failure mode
	373	
	250	 IEC 1355/14

Table 22 – Effect of the area of the conductor

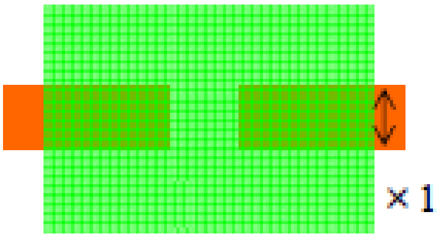
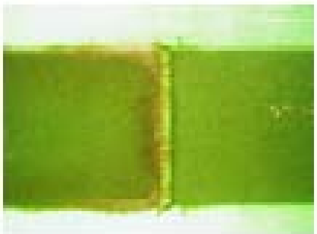
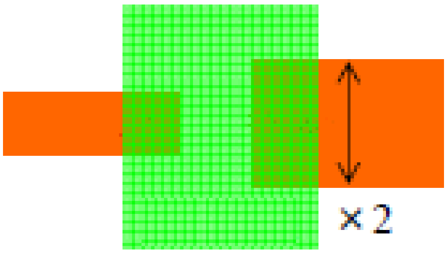
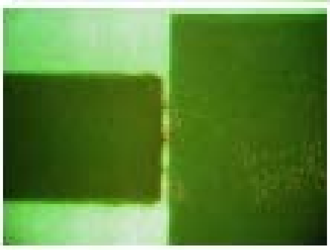
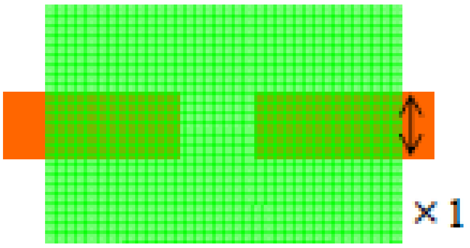
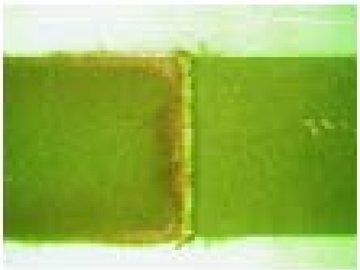
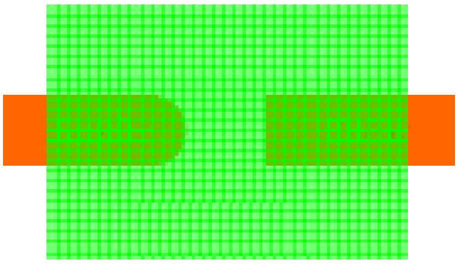
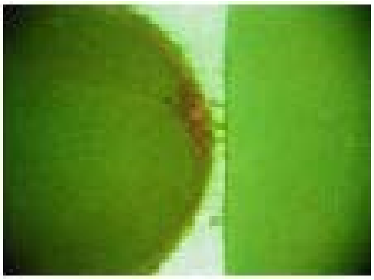
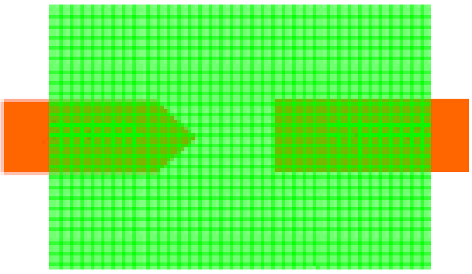
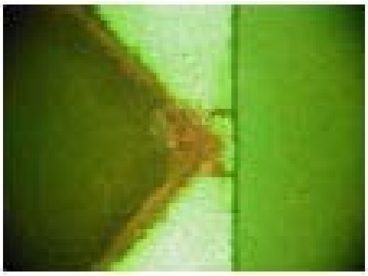
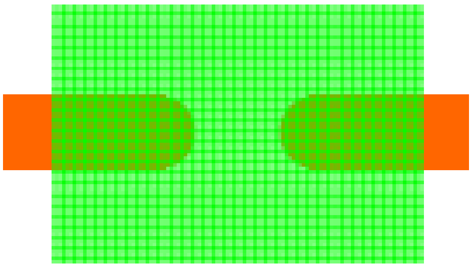
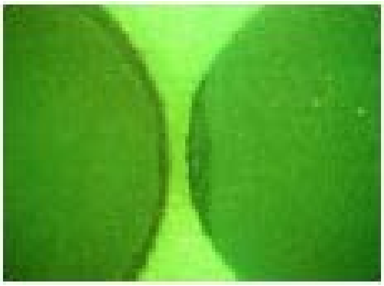
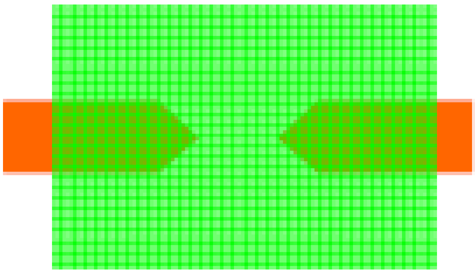
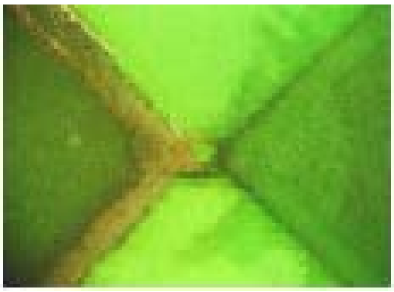
Position and form	MTTF (h)	Failure mode
	432	
	197	 IEC 1356/14

Table 23 – Effect of the shape of the tip of the electrodes

Position and form	MTTF (h)	Failure mode
	432	
	484	
	257	
	450	
	590	

IEC 1357/14

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T. AWANO, T. ISHIKAWA,T,. YOSHIMITSU and K. TAKAGI, *Insulation Reliability of Glass Cloth Material Based Copper Clad Laminates*, Printed Circuit World Convention, pp. 47-2-16, 1987

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Annex A
(informative)

Life evaluation

A.1 Voltage dependence of life

The voltage dependence of the voltage dependent life (t_{V}) shows good linear dependence when plotted on a log-log chart.

$$t_{\mathrm{V}} = K_{\mathrm{V}} V^{-n} \tag{A.1}$$

K_{V}: constant.

This relation is applicable to the case the applied voltage is not constant but pulses. It is known that life in the applied strain and repeated cycle characteristics can also be in a linear relation when plotted on a log-log chart. The tangent of the line, n, is 1 to 2 in the case of degradation caused by migration, which is much smaller than the degradation caused by failures in the insulation defect at the rotation mechanism or by cables, where n is more than 5 or even in excess of 20. The tangent may differ by the applied voltage in the case of the rotation mechanism failure. This change of n means that the failure mechanism is different for the relevant n value regions. Degradation is not very significant in the case where voltage stress is low but it simply means that the stress condition is near the threshold value but the failure mechanism itself is the same.

A.2 Temperature dependence of life

The temperature dependence of the temperature dependent life, t_{T}, is expressed in the following equation.

$$t_{\mathrm{T}} = K_{\mathrm{T}}{}^{E_a / KT} \tag{A.2}$$

K_{T}: constant.

It is possible to obtain the activation energy E_{a} (eV) of the failure from the tangent of the line. The apparent activation energy is about 0,1 eV to 1 eV. If the gas constant (R = 1,987 cal(mol-K)) is used in the equation, the unit of activation energy is cal/mol.

A.3 Humidity dependence of life

A.3.1 General

It is not easy to understand the relation of humidity life t_{H} and humidity (H) as the experimental data is not well organized. This relation can be expressed as

$$t_{\mathrm{H}} = K_{\mathrm{H}} H^{-m} \tag{A.3}$$

K_{H}: constant.

m is generally 3 to 6. The semi-log plot with a linear horizontal axis of humidity is expressed as

$$t_{\mathrm{H}} = K_{\mathrm{H}} \exp(-\lambda H) \tag{A.4}$$

K_H: constant,

λ: failure rate.

Now only data at a relatively high humidity range has been obtained but lifetime in the semi-log graph shows linearity to the humidity. By comparing the estimated lifetime at a low humidity, the estimated lifetime in a semi-log plot is slightly shortened as compared to a linear plot. Since the semi-log plot is evaluated the safety side of the estimated lifetime, in some cases the semi-log plot is adopted as the humidity dependence of life.

A.3.2 Relation between temperature (°C), relative humidity (%RH) and vapour pressure (hPa)

The relationship is shown in Table A.1 and Figure A.1.

Table A.1 – Vapour pressure at test temperature and relative humidity

Temperature/relative humidity	**(Saturated) Vapour pressure** (hPa)	**Temperature/relative humidity**	**(Saturated) Vapour pressure** (hPa)
40 °C/85 %RH	62,7	40 °C/90 %RH	66,4
60 °C/85 %RH	169,4	60 °C/90 %RH	179,4
85 °C/85 %RH	491,5	85 °C/90 %RH	520,4
110 °C/85 %RH	1 218	–	–
120 °C/85 %RH	1 687	–	–
130 °C/85 %RH	2 295	–	–

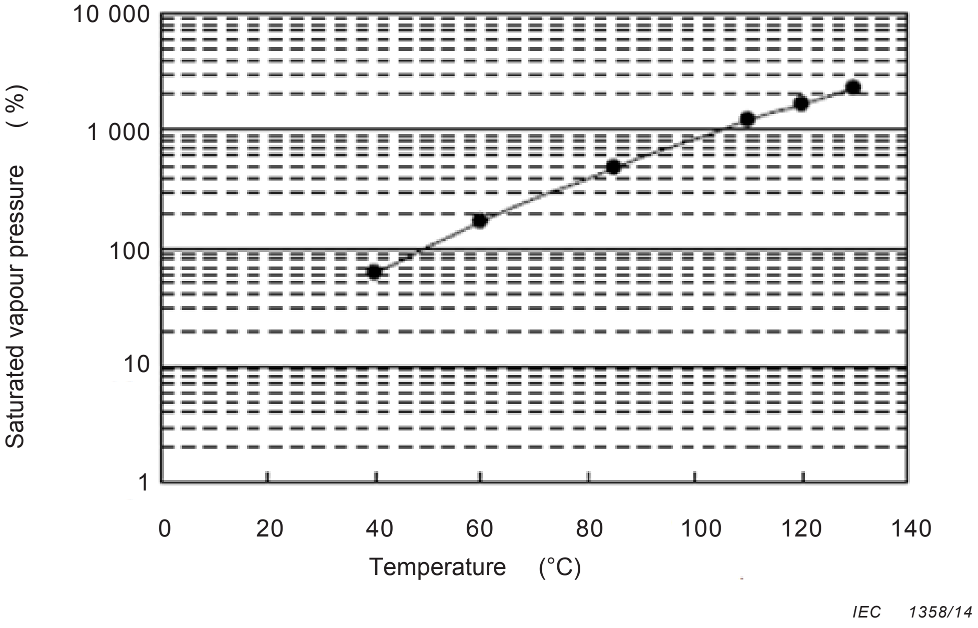


Figure A.1 – Temperature and saturated vapour pressure

A.4 Acceleration test of life and acceleration factor

The life L in an accelerated life test is usually expressed as equation (A. 5) based on the Isling model.

$$L = t_V t_T t_H = KV^{-n} H^{-m} \exp(Ea/kT) \tag{A.5}$$

The acceleration factor A_F for test conditions of voltage V, temperature T and humidity H compared to the actual field environment of applied voltage of V_0, temperature T_0 and humidity H_0 is expressed in equation (A.6).

$$\mathrm{A_F} = (\mathrm{V/V_0})^{\mathrm{n}}(\mathrm{H/H_0})^{\mathrm{m}}\exp\left\{\mathrm{E_a/k}\left(\frac{1}{\mathrm{T_0}}-\frac{1}{\mathrm{T}}\right)\right\} \quad A_F = (V/V_0)^n (H/H_0)^m \exp\left\{E_a/k\left(\frac{1}{T_0}-\frac{1}{T}\right)\right\} \tag{A.6}$$

A.5 Remarks

It should be noted that Equation (A.6) is valid only when the degradation mechanism is the same for the accelerated test and in the failures in the field. The life in an environmental test is very short, with a status where dew formation is observed on a part of specimen, comparative to life in actual use in the field where dew formation is not usually observed. When a test is made to evaluate life with a specimen which has electrodes on the surface and is not resin coated for surface protection, the test should be made by the dew cycle test especially when the effect of dew formation on life shortening is the purpose of the test.

There is a chance of short circuit if a foreign metal object is attached to a specimen, and the presence of a fibriform substance between electrodes may induce metal ion migration along the fibre of the substance. Regular voltage acceleration is not applicable in such a case.

There is a risk that the absorption of water vapour by the dust and a foreign substance on the surface of a specimen may result in partly high humidity condition and migration may be induced.

Annex B
(informative)

Measurement of temperature-humidity

B.1 Measurement of temperature and humidity

B.1.1 General

It is important to use the same method used for monitoring the temperature and humidity in a test chamber for the check of the temperature and humidity. A most commonly used method is the use of a dry-and-wet bulb hygrometer. There are many other types of sensors in the market, however, the sensor to be used should be confirmed of the traceability with nationally approved standard meters. Systems and requirements imposed on hygrometers used in a steady-state temperature-humidity test chamber are stated below.

B.1.2 Commonly used temperature-humidity measurement systems and their merits

The dry-and-wet bulb hygrometer is usually used as it satisfies most of the requirements in the measurement. A platinum temperature sensing resistor (Pt 100 Ω), or a thermocouple T (copper-constantan) is usually used for the temperature detection as illustrated in Figure B.1. The problem with the use of a dry-and-wet bulb system is the necessity of supplying water to the wet bulb by means of a piece of cloth called wig. There may be the limitation of a long testing time due to the dirt attached to the wig suppressing the proper supply of water to the wet bulb. Various meters used in a steady-state temperature-humidity test chamber are listed in Table B.1.

B.1.3 Requirements for the humidity measurements in a steady-state temperature-humidity test chamber

1) Capability of measuring low to high ranges of both humidity and temperature.
2) Reliability of measurement of 95 % for reproducibility, drift, hysteresis and time variation, and of accuracy of several percentages for relative humidity.
3) Possibility of continuous measurement.
4) Possibility of conversion of data to electric signals for display, record, and computation and control.
5) Sensors should be small and should not affect the measuring environment.
6) Quick response to changes of environment in the chamber.
7) Low running cost and capability of long time measurement.
8) Easy maintenance or change of sensors.

B.2 Typical methods of temperature and humidity measurement

B.2.1 General

The most common measurement system uses the dry-and-wet bulb system and platinum temperature measurement resistors (Pt 100 Ω), or a thermocouple (copper-constantan). They are not expensive and can measure the ranges required for a test with the required accuracy.

B.2.2 Checking procedure for temperature measurement

Table B.1 – Merits of and remarks on various humidity measuring methods (applicable to steady state temperature-humidity tests)

Humidity measurement method	Drawbacks and advantages
1. Psychomotor	Drawbacks: 1) Need for conversion function from measured wet-and-dry bulb temperature to relative humidity 2) Need for wick installation for wet bulb temperature detection 3) Need for automatic water supply to wick 4) Need for replacement through deterioration of water absorption ability 5) Affection to humidity value inside of chamber by wick water Advantages: 1) Inexpensive 2) Easy to use 3) Easy to revise
2. Dew point recorder	Drawbacks: 1) Costly and too large 2) Need for thermal insulation and calefaction on sampling routes 3) Need for conventional junction from dew-point to relative humidity 4) Need for cleaning of mirror surface area Advantages: 1) Wider measurement range (especially on low humid areas) 2) High accuracy
3. Capacitance humidity sensor	Drawbacks: 1) Need for regular revision to keep measurement accuracy 2) Characteristics drift by dirtiness 3) Slow recovery from condensation (need for filter installation) 4) Accidental error due to organic solvent Advantages: 1) High quality in response 2) High quality in linearity and stability 3) No water supply mechanism 4) Use available for high-humidity area 5) Compact size 6) Easy to control due to sequential measurement of temperature and humidity

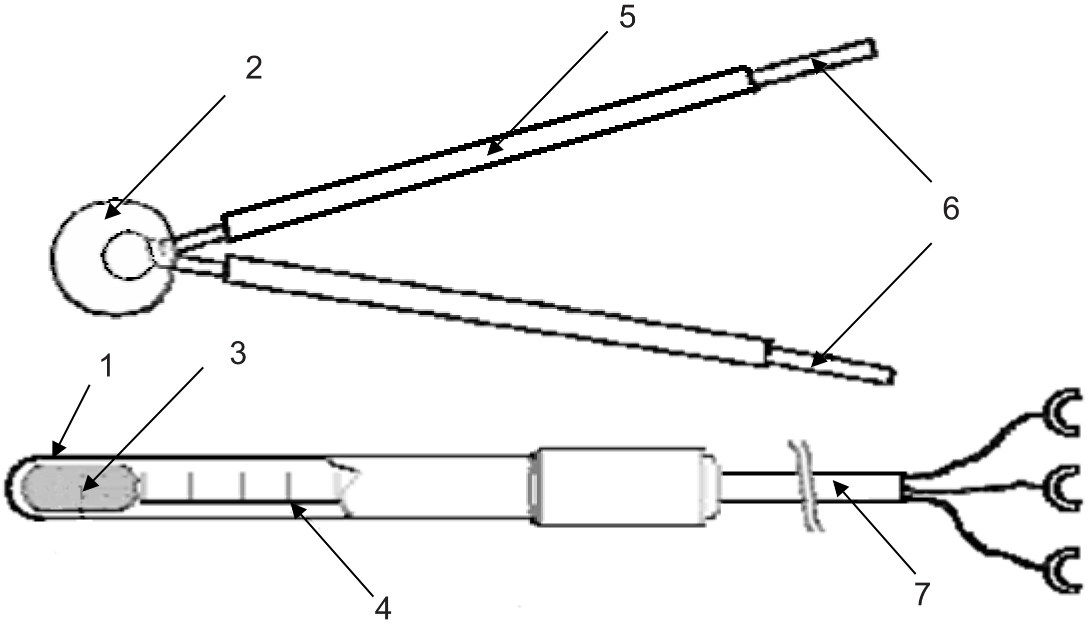
1) Decide the requirement for the temperature measurement. First select the temperature range for the measurement. If not specified, the lower or upper limit temperature of the test equipment may be selected.
2) Take out all the specimens left in the test chamber.
3) Select the temperature sensors appropriate to the test chamber. Prepare the same sensors as used in the test chamber, generally speaking, a thermocouple sensor (copper-constantan) or a platinum resistor (Pt 100 Ω) for a low to medium temperature range, and a thermocouple (chromel-alumel) for a high temperature range (> 200°). The accuracy of the sensor should be equal to or better than that used in the test chamber (response time of minimum of 10 s to maximum of 60 s). The tip of the sensor (chromel-alumel) should be of a diameter of 3 or 5 and of a wire diameter of 0,32 mm. The platinum resistor (Pt 100 Ω) is used for the three wire type with a protection tube.
4) Set at a proper position as shown in Figure 15 for more than four places in symmetric positions to the centre of the chamber. The wind velocity near the humidity sensor should be considered.

5) Connect the sensors to recorders which are calibrated.

6) Take a reading of the sensor(s) for a time of 30 min for every 1 min after the entire system reaches a stable state and calculate the temperature as illustrated in Figure B.1. Derive the average maximum temperature (humidity) and the average minimum temperature (humidity) relevant to the average temperature (humidity), and confirm the temperature is in the range of the temperature distribution the test equipment is designed for (re-calibrate if the temperature is not in the range the equipment is designed for).

B.2.3 Checking procedure for humidity measurement

The basic procedure is the same as that for the temperature measurement. The dry-and-wet bulb method is used in many systems as the equipment is fairly well suited for the air-tight environment of a test chamber of not very large volume. (Most of these systems use the dry-and-wet bulb method.) It is possible to obtain the relative humidity using the relative humidity list with the dry-and-wet bulbs but it is necessary to select a proper method based on the air flow hitting the bulbs.



IEC 1359/14

Key

1 Guard pipe (SUS304)

2 Brass ball

3 Temperature measuring element

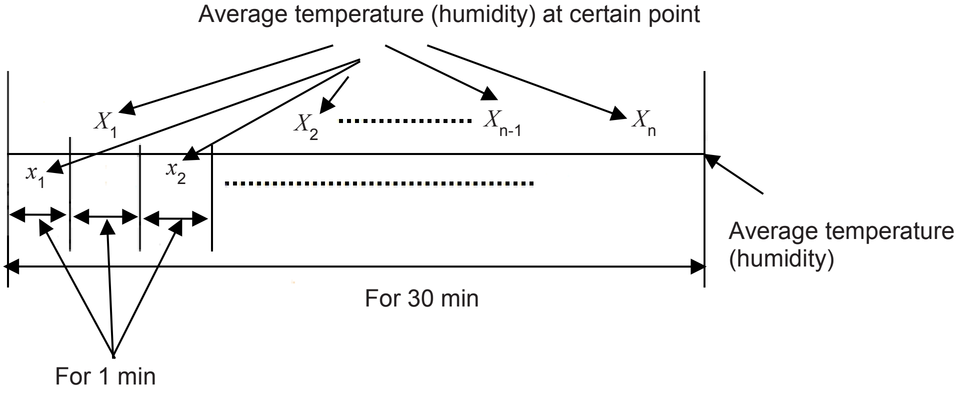
4 Empty in case C
Filled with MgO in case D

5 Covering

6 Thermocouple wire

7 3-core lead wire

Figure B.1 – Specification of sensors used in the test and their shapes



IEC 1360/14

Figure B.2 – Calculation method of the average temperature (humidity), the average maximum temperature (humidity) and the average minimum temperature (humidity)

X_1, X_2,... X_n, x_1, x_2, ... x_m are the average temperature (humidity) at each measurement point. The average temperature (humidity) is the average of all measurement points. The average temperature (humidity):

$$(X_1+X_2+\ldots+X_n+x_1+x_2+\quad+x_m)/(n+m) \tag{B.1}$$

Where

$n+m \leq 30$.

X_1, X_2,... X_n are above the average temperature (humidity),and x_1, x_2, ...x_m are beneath the average temperature(humidity). So the average maximum temperature (humidity) and the average minimum temperature (humidity) are:

The average maximum temperature (humidity) is:

$$(X_1+X_2+\ldots+X_{n-1}+X_n)/n \tag{B.2}$$

Where

n is the number of X.

The average minimum temperature (humidity) is:

$$(x_1+x_2+\ldots+x_{m-1})/m \tag{B.3}$$

Where

m is the number of x.

B.2.4 Derivation of temperature in a chamber

The absolute humidity, D, is:

$$D = (H/100)\{804/(1+0{,}00366t)\}(e_s/p_0)\ \ [\text{g/m}^3] \tag{B.4}$$

where H is the relative humidity (RH %), t is the temperature (°C), P_0 is the standard pressure (Pa), and e_s the saturated vapour pressure (Pa).

e_s is given as a numerical scheme in ISO 4677-1. The relative humidity and absolute humidity can be calculated from the above equation (B.4). The relative humidity should be calculated from the Splung equation given below (B.5) from the readings of the dry-and-wet bulbs of a hygrometer. This equation is also adopted in ISO 4677-1.

$$e = e_s^{'} - A(P/755)(t - t^{'}) \qquad \text{(B.5)}$$

where t' is the temperature of wet bulb (°C), e is the vapour pressure (Pa), e'_s is the saturated vapour pressure (Pa) at t' (°C), P is the air pressure (Pa), and A is a factor (A = 0,5 when the wet bulb is not frozen and A = 0,55 when the bulb is frozen).

The relative humidity H can be obtained from the equation:

$$H = \frac{e}{e_S} \times 100 \ \ [\%] \qquad \text{(B.6)}$$

An air flow of over 2,5 m/s to the wet bulb of a wet-and-dry bulb hygrometer is necessary to use equation (B.6). Another equation for a wet-and-dry bulb hygrometer is needed for calculation of the humidity in case such an air flow is not available. The Japan Association of Test Equipment has published the following Pelunter equation for this purpose in JTM K 01 .

$$\mathrm{e} = \mathrm{e_W\text{-}}\lambda\mathrm{P}(1 + \mathrm{T_W/B})(\mathrm{T_D\text{-}T_W}) \qquad e = e_W - \lambda P\left(1 + \frac{T_W}{B}\right)(T_D - T_W) \ \ [\mathrm{Pa}] \qquad \text{(B.7)}$$

where e is the vapour pressure of the air in question (Pa), e_W is the saturated vapour pressure of the wet-bulb (Pa), T_D is the temperature of the dry bulb (°C), T_w is the temperature of the wet bulb (°C), and B and λ are constants (see Table B.2).

Table B.2 – Derivation of relative humidity from dry-and-wet bulb humidity meter

Wind speed around wet bulb (m/s)	**Non frozen wet bulb**		**Frozen wet bulb**	
	λ	B	λ	B
0 to 0,5	0,001 200	610	0,001 060	689
1 to 1,5	0,000 800	610	0,000 706	689
2,5 or over	0,000 656	610	0,000 579	689

B.2.5 Definition of relative humidity in HAST

Air can take in additional water vapour if the water vapour pressure is less than the saturated water vapour pressure up to the saturation. The ratio of the actual water vapour pressure to the saturated vapour pressure expressed in % is the relative humidity of the air in question. The relative humidity, φ, is expressed in the equation (B.8) with a water vapour partial pressure of P_W at temperature T and the saturation vapour pressure P_s at the same temperature T, as:

$$\Phi = \frac{\mathrm{P_W}}{\mathrm{P_S}} \times 100 \quad \phi = \frac{P_W}{P_S} \times 100 \ \ (\ \%\mathrm{RH}) \qquad \text{(B.8)}$$

Wet air may be considered as a mixture of dry air without any water vapour and of water vapour. The air pressure of the wet air, P, can be expressed from the law of Dalton (law of partial pressure) as the sum of both of the partial pressures of the dry air, P_a, and of the water vapour pressure, P_W, as

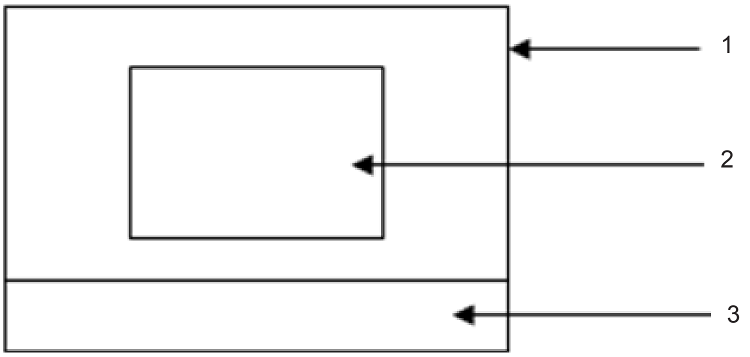
$$\mathrm{P} = \mathrm{P_a} + \mathrm{P_W} \quad P = P_a + P_W \tag{B.9}$$

Let the dry air of saturated air with $P_a = 0$, then

$$\mathrm{P} = \mathrm{P_W} = \mathrm{P_S} \quad P = P_W = P_S \tag{B.10}$$

A local region (the working space in Figure B.3) of a space of saturated air with temperature T, where it is further heated to T', results in an unsaturated water vapour region. Let P'_S be the saturated water vapour pressure in this heated region and P_S the saturated water vapour pressure surrounding the heated region. Then the relative humidity, φ', in a HAST environment is defined as

$$\phi' = \frac{P_S}{P_S'} \times 100 \; \Phi' = \frac{\mathrm{P_S}}{\mathrm{P_S}'} \times 100 \;\; (\%\mathrm{RH}) \tag{B.11}$$



IEC 1361/14

Key

1 HAST chamber
Temperature in HAST chamber T
Saturated water vapour pressure in HAST chamber P_S

2 Working space
Temperature in test area T'
Saturated water vapour pressure in test area P'_S

3 Humidifying water

Figure B.3 – Relative humidity in a pressurized chamber

The direct measurement method of humidity in the environment used in HAST is not well established yet the test method is described in IEC 60068-2-66.

The relative humidity in this range is estimated from the indirect measurement of the temperature measurement and the dry-and-wet bulb method.

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