Report 2

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

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

1. Introduction

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

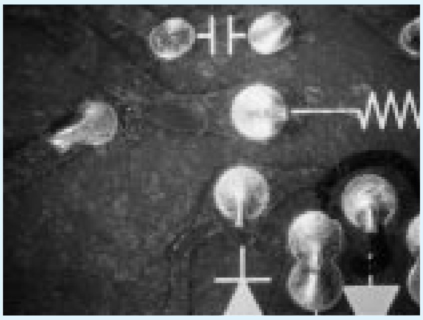
On the other hand, a number of accidents caused by tracking have already been reported to date. Failure analysis is crucial to an investigation into the cause of these accidents and to a study of countermeasures. To that end, the authors of this report have performed failure analysis to uncover the causes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

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

2. Example of failure

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

(a) Appearance of burned area



(b) Before tracking has occurred

Photo 1 Example of failure

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

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

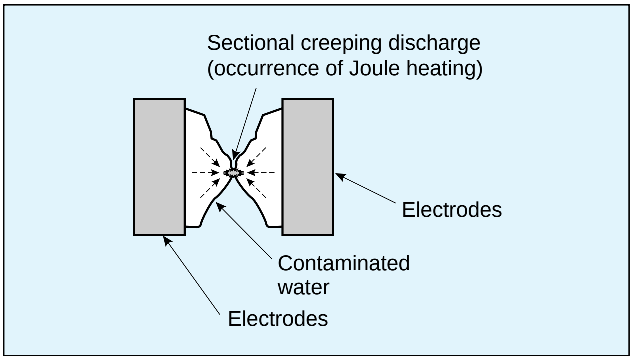

Fig. 1 Mechanism in the occurrence of tracking

4. *Test methods*

Fig. 2 shows a schematic diagram for these tests, and Table 1 presents test conditions. The test methods are based on IEC 60112 ("Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions"), focusing on evaluation tests mainly for electronic equipment. The test conditions use the local commercially-available power consisting of 50Hz current and low voltage. Test specimens consist of opposing electrode circuit patterns on PCBs. The space between electrodes was varied to check the correlation of occurrence at each distance. This approach yielded a detailed pattern for evaluation, and also since the electrode shape corresponds to the distance between electrodes, we used comb-shaped electrodes. A phenol resin with a high ratio of energy with which carbon is generated in integrated energy at pyrolysis ($\Delta Hc/\Delta H$) was selected as the PCB material. For the electrolytic solution, we used the 0.1% NH_4Cl prescribed in the IEC tracking test method, and we studied the effects of using different concentrations of electrolytic solutions as well.

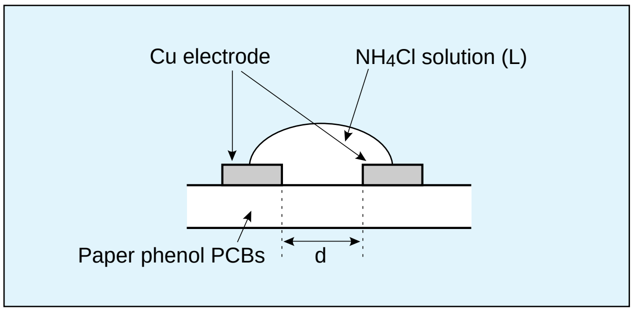

Fig. 2 Test Method

Table 1 Test conditions

Electrode gap	d = 0.165, 0.318, 0.635 mm
Electrolytic solution	NH_4Cl solution 0.1, 0.5, 1.0, 2.0 weight % (0.1%:395Ω • cm at 23°C) Capacity L = 1 μL
PCB material	Paper phenol (CTI:600V, Min.)
Electrode material	Cu
Surface processing	None
Application time	10 sec./1 drop
Tracking determination	Min. 1 Amp. leakage current

5. *Test results and considerations*

5-1 The relationship between electrolytes and electrode spacing

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

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

The graphs in Fig. 3 investigate the relationship between the voltage when tracking occurred (CTI, Comparative Tracking Index) and the concentration of the electrolytic solution (electrical conductivity) after 50 drops. Fig. 4 shows the results of that investigation. At a concentration of around 0.1%, there was a large change in the CTI value due to a change in concentration. As a result of this pattern, the graphs converge as the concentration increases, and at above 1.0 to 2.0 percent, changes in concentration had little effect, obtaining a tendency for the CTI values to become almost uniform. This is thought to indicate uniformity of electrical discharge. When we look at the electrolytic strength (V/mm) as in the table annexed to Fig. 4, tracking occurs at roughly the same time at a concentration of 2.0 percent for electrode intervals from 147 to 173 V/mm. Also, as we can see in Fig. 5, the CTI value is roughly in direct proportion to the electrode gap at a concentration of 2.0 percent. In other words, in this region of convergence, we can see that electrical discharge depends on the electrolytic strength (V/mm) such as seen in the gas discharge phenomenon. However, even if the distance between electrodes is changed, if there is not an analogous change in the overall shape in the relative distance between the electrodes, we don't believe that the results obtained will be proportional to the changes in the distance between the electrodes. As Fig. 6 shows, concurrent to low concentrations such as 0.1 percent, the differences in the electrode gap can be deemed to have a significant effect.

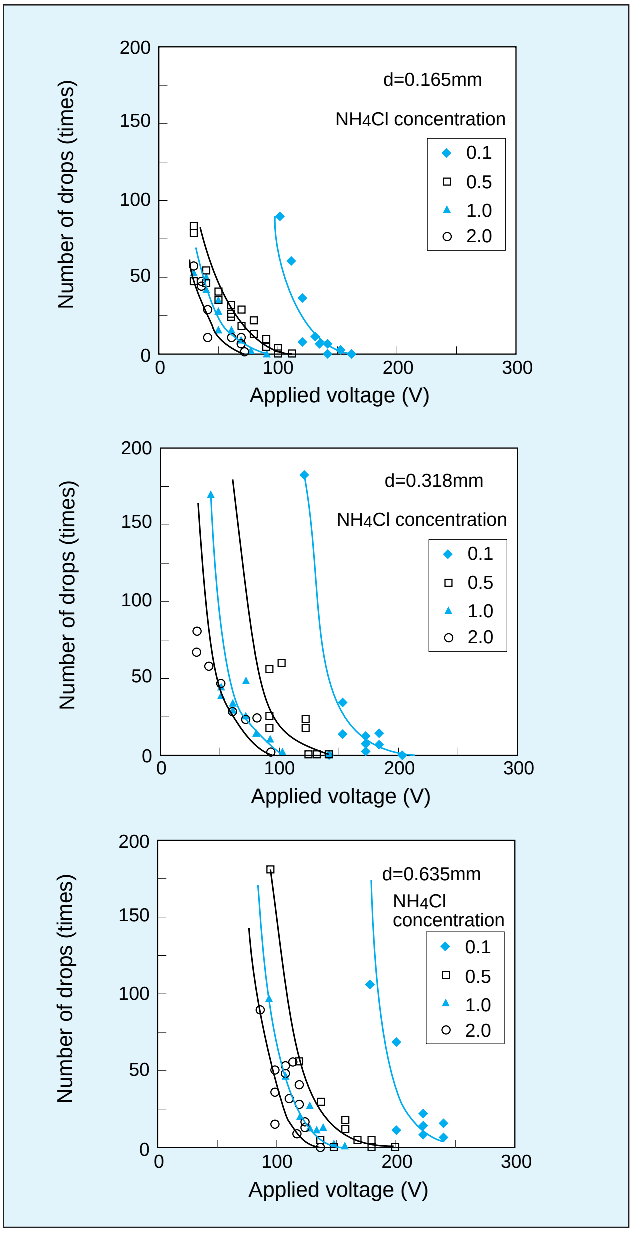

Fig. 3 Tracking voltage features

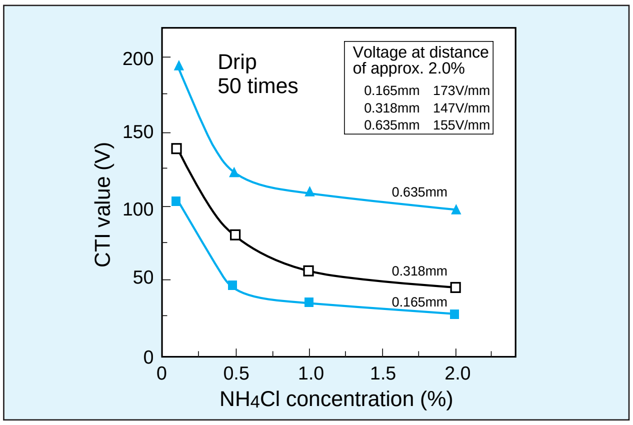

Fig. 4 Electrolytic solution concentration – CTI characteristics

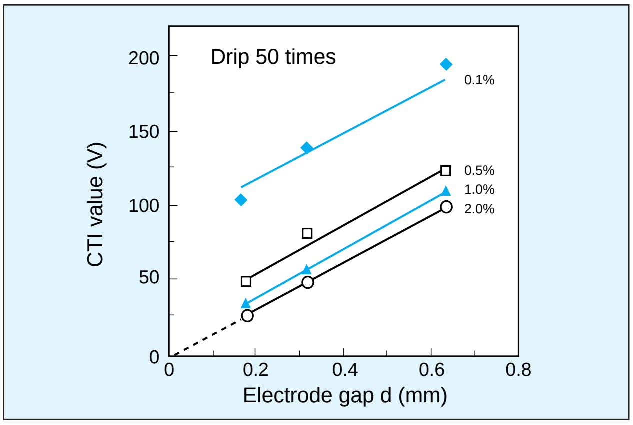

Fig. 5 Electrode gap – CTI characteristics

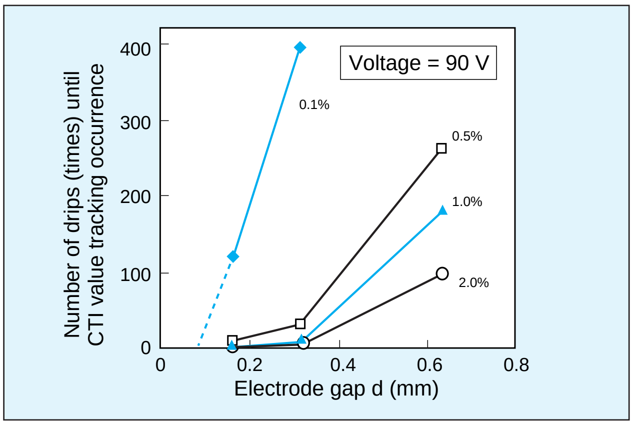

Fig. 6 Relationship between electrode gap and number of drips until tracking occurs

5-3 The relationship between frequency and current

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

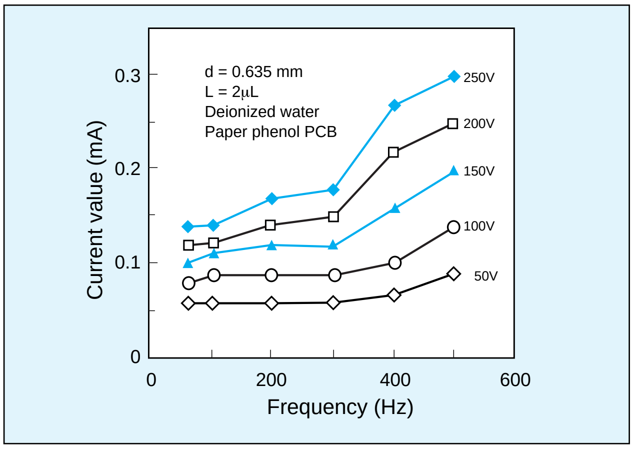

Fig. 7 Frequency-Current characteristics

5-4 The relationship between wetness and voltage

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

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

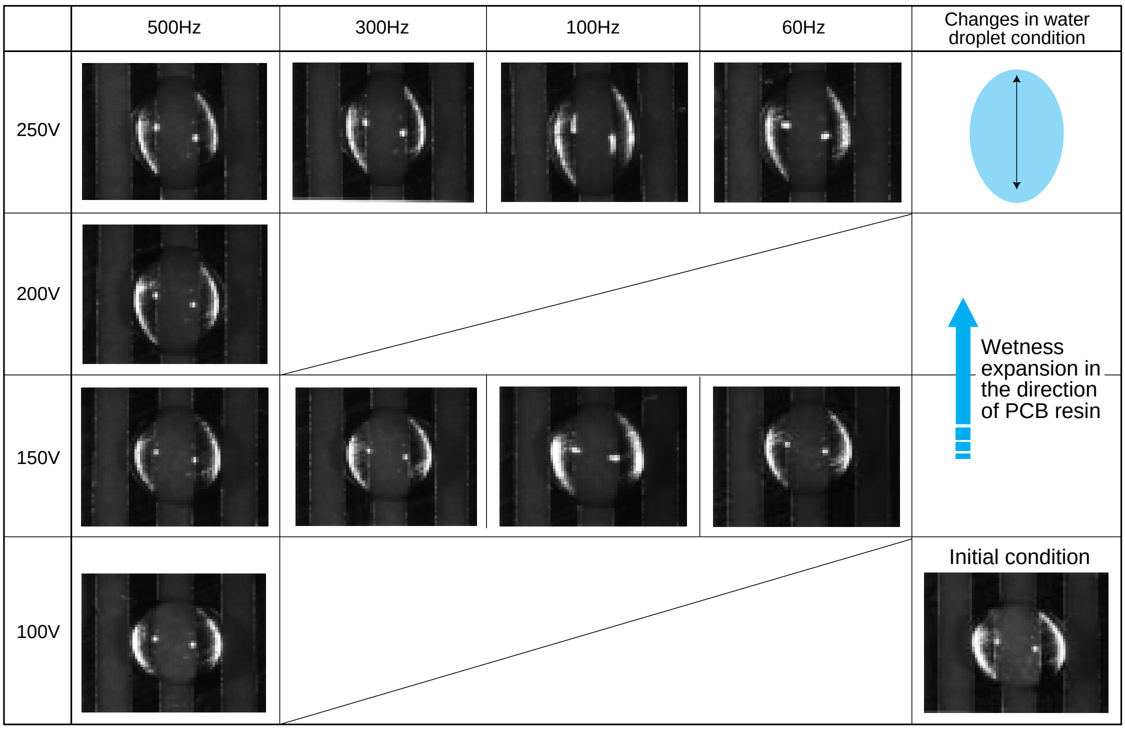

Photo 2 Changes in wetness due to voltage – frequency

6. Summary

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

(1) For electrode gaps in the range of 0.165 to 0.635 mm, with a high concentration (1 to 2%) of electrolytic solution of NH_4Cl, the concentration dependence of the CTI values decreased, and the relationship between the electrode gap and the CTI value approached approximately direct proportion.

(2) At low concentrations such as 0.1% NH_4Cl electrolytic solution, variances in the electrode gap have a greater affect on the occurrence of tracking.

(3) Leakage current affects frequency, and the significance of that influence is connected to the level of voltage applied.

(4) PCB wetness expands due to applied voltage, but is unaffected by frequency.

7. Future themes

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

Terminology

***1 Tracking**

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

[Bibliography]

1) Japanese Standards Association, "JIS C 2134: Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions", Japanese Standards Association, 1996.
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3) Boxue Du, Akio Suzuki and Shigeo Kobayashi, "Tracking Resistance of Organic Insulating Materials with Direct Voltage 2", DEI-96-7-14, The Institute of Electrical Engineers of Japan, p.63-72, 1996
4) IEC 60112, "Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions", 1979
5) UL 746A, "Comparative tracking index and comparative tracking performance level categories of electrical insulating materials", 1995