Investigating the effects of packaging materials on products

Hiroko Inoki*, Yuichi Aoki*, Hirokazu Tanaka*, Shigeharu Yamamoto*

Modern packaging materials emit naturally-occurring gas that can corrode the metal parts of the products. To investigate this problem, we developed methods for testing and evaluating the Outgas. Our investigation revealed the source of corrosion to be sulfuration due to hydrogen sulfide (H_2S) emitted by the packaging materials. Sulfuration varies with temperature, set-up conditions, and the quantity of the Outgas. To insure product reliability, care must be taken with the type of packaging materials used, the packaging method, and the temperature during shipping.

1. Introduction

With the introduction of the Product Liability law, maintaining and supervising product reliability has become an urgent necessity. Modern products have attained very high levels of product reliability, but product failure may also result from packaging and shipping conditions[1]. Various reports have been published concerning the packaging problem, and awareness has been growing of the impact packaging materials have on the products they contain[2, 3].

On the other hand, burgeoning concern for environmental problems has resulted in serious efforts to recycle paper and to simplify packaging. Efforts to replace styrofoam with corrugated cardboard as a cushioning material have been gaining ground due to the lack of satisfactory techniques for recycling styrofoam. These changes in packaging can be seen as factors having an impact on the products[4].

Accordingly, for this report we focused our attention on the corrugated cardboard used in packaging, shipping, and storing products, and we investigated the effects of temperature and various types of corrugated cardboard on products.

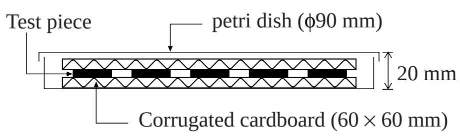
2. Test method considerations

Sulfuric acid is used in the refinement of pulp, which is the raw material for corrugated cardboard. Residual sulfuric acid ions in the corrugated cardboard produce H_2S gas, and this gas is widely known to cause discoloration and degradation[2]. We investigated methods of testing the affects on metal of gases emitted from various kinds of corrugated cardboard.

2-1 Preliminary Test 1: determining specimens

We performed preliminary testing to determine the types of corrugated cardboard and the test pieces to be used in the tests. Table 1 shows test conditions. The test method consisted of holding a test piece between two sheets of corrugated cardboard (60 × 60 mm) and exposing it to high temperature. We selected 80°C with 24-hour exposure for test conditions to reflect the transportation environment encountered by products shipped via sea freight[5]. Table 2 shows test results.

Table 1 Test conditions for Preliminary Test 1

Corrugated cardboard	11 types
Test pieces	Silver-plated, copper, aluminum, stainless steel
Test conditions	80ºC, 24 hours
Test conditions	

*Environmental Test Technology Center

Table 2 Test results for Preliminary Test 1

Corrugated cardboard				Results (discoloration)	
Application	Type	Packaged item	Producing country	Silver	Copper
Electrical equipment	A*	Transformer	Japan	×	△
	B	Power supply	Japan	×	△
	C*	Power supply	Philippines	×	△
	D	Power supply	Japan	×	△
	E	Instrument	Japan	×	△
Electronic parts	F*	IC	Thailand	△	○
	G	IC	Japan	○	◎
	H	IC	USA	△	○
Office equipment	I*	Printer	Japan	△	○
	J	Computer	Malaysia	△	○
	K	Computer	Singapore	○	○

Note 1: Asterisks (∗) indicate selected for main test
Note 2: Discoloration severity (as judged by visual inspection)
◎ No discoloration × Moderate discloration
○ Slight discoloration △ Severe discoloration

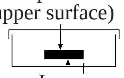
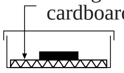
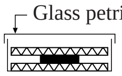
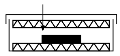
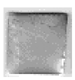
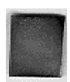
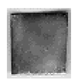
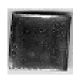
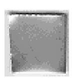
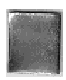
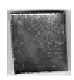
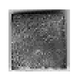
Silver-plated and copper pieces showed discoloration, while no discoloration was observed on aluminum or stainless steel pieces. Therefore, we selected silver-plated pieces for testing to facilitate comparing the different types of corrugated cardboard, as the silver-plated pieces sustained the most severe discoloration. Furthermore, electrical products were strongly affected by corrugated cardboard packaging, while electronic products and office equipment were relatively unaffected. Since there was a tendency for comparable levels of discoloration to occur within the same type of application, we ran this test by making random checks of one or two items in each application category of corrugated cardboard.

2-2 Preliminary Test 2: set-up condition considerations

We performed testing to determine the discoloration effects of set-up conditions on silver-plated test pieces. The test method consisted of exposing the test pieces to a temperature of 80°C for 40 hours, removing the silver-plated test pieces, and visually inspecting both the top and bottom surfaces. Table 3 shows the test methods and results.

A comparison of the surfaces of the silver-plated test pieces showed that surfaces not in contact with the corrugated cardboard were much more severely discolored than contact surfaces. Discoloration is presumed to have progressed due to the silver-plated test pieces being exposed to the convection currents of the gas generated. On the other hand, lack of discoloration on the surfaces in contact may be presumed to have resulted conversely from the lack of exposure to the convection currents. Therefore, the set-up was arranged to facilitate exposure to the convection currents of the gas, promoting ease of evaluation of the corrugated cardboard.

Table 3 Preliminary Test 2: A comparison of test results under differing conditions

		1. None	2. Inserted on one side	3. Inserted on both sides	4. With gap
Set-up 4 conditions		Silver-plated test pieces (upper surface)  Lower surface	Corrugated cardboard 	Glass petri dish 	Gap between surface and cardboard 
Results – External	Upper		 Non-contact surface	 Contact surface	 Non-contact surface
Results – External	Lower		 Contact surface	 Contact surface	 Contact surface
Results – Characteristics		• No discoloration	• Slight discoloration in contact surface • Advanced discoloration in non-contact surface.	• Slight discoloration in contact surfaces	• Slight discoloration in contact surface • Very advanced discoloration in non-contact surface

Note: "Contact" and "non-contact" indicate the condition of the silver-plated test piece in relation to the corrugated cardboard.

3. Test methods

We then tested the four types of corrugated cardboard (A, C, F, & I in Table 2) that had been selected with the preliminary tests. Table 4 shows test conditions, and Fig.1 shows test methods. A weight of 30 g was deemed suitable for determining the level of corrosion caused by corrugated cardboard. Each type of corrugated cardboard was put into 900 mL glass bottles, and then a silver-plated test piece was dangled from the lid, which was sealed. These specimens were then exposed to 40°C or 80°C heat for 100, 200, or 300 hours. The silver-plated test pieces were hung so that they would dangle at a distance of 2 to 3 mm above the corrugated cardboard. Each type of corrugated cardboard was evaluated by observing the appearance of the silver-plated test piece, by EPMA analysis*1, by contact resistance measurement, and by solderability testing by the wetting balance method.*2

Table 4 Test conditions

Test conditions	40°C, 80°C
Test time	100, 200, 300h
Corrugated cardboard	4 types (A, C, F, & I in Table 2) Weight: 30 g
Test pieces	Material: Silver-plated test pieces Dimensions: 50 × 20 × 0.2 mm Plating thickness: 3µm

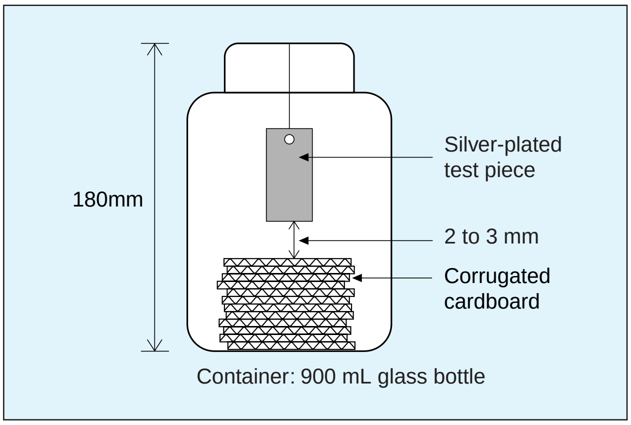


Fig. 1 Test method

4. Results and observations

4-1 Appearance

The silver-plated test pieces were scanned, and the scanned images were examined. Fig. 2 shows test results.

Discoloration was much more pronounced at 80°C than at 40°C, and the test confirmed that the higher the temperature, the greater the discoloration of the test pieces. This correlation stems from the temperature's effect of increasing the sulfuration reaction speed, but we hypothesize that the temperature may also increase the quantity of gas produced. One characteristic of the discoloration was that it progressed from the four corners of the silver-plated test pieces. In comparing the effects of the different types of corrugated cardboard, type C (for electrical equipment and power supply) was found to cause the greatest discoloration.

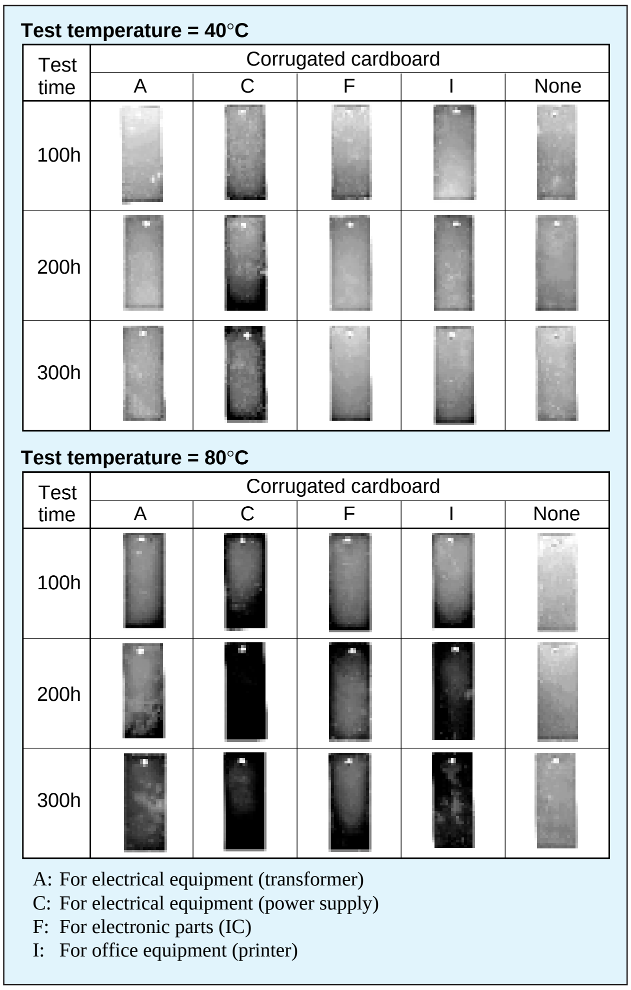


Fig. 2 Appearance results

4-2 Surface analysis

We performed EPMA analyses on the surfaces of the silver-plated test pieces. The analytical method consisted of measuring the degree of discoloration at the four corners (where it was more severe) of each silver-plated test piece. We then found the average value for the level of sulfuration (by weight percent). Fig. 3 shows the measurement results for the level of sulfuration by EPMA analysis.

Using EPMA analysis, we checked the sulfuration of the silver caused by each type of corrugated cardboard. The greatest level of sulfuration was found in test pieces with the greatest discoloration, i.e., pieces exposed to corrugated cardboard type C (for electrical equipment and power supply). This finding clearly demonstrated the relationship between sulfuration and discoloration. Furthermore, the level of sulfuration was greater at 80°C than at 40°C, indicating that higher temperature accelerates the sulfuration.

4-3 Measuring contact resistance

We measured the contact resistance of the surfaces of the silver-plated test pieces. The test method consisted of applying contact pressure of approximately 0.098N (10gf) at constant load with an Au probe with curvature radius R = 0.8 mm and measuring with a milli-ohmmeter. Contact points were located at the four corners of the specimens, the same places at which EPMA analyses were done, and we calculated the average measured values. Fig. 4 shows the test results.

The characteristics of the changes in contact resistance due to the different types of corrugated cardboard showed roughly the same tendencies as the degree of discoloration and the level of sulfuration, leading to the conclusion that the results were due to sulfuration. Items with extremely high resistance values attained close to 10 ohms. This level of resistance can easily cause failure due to defective contact and defective soldering.

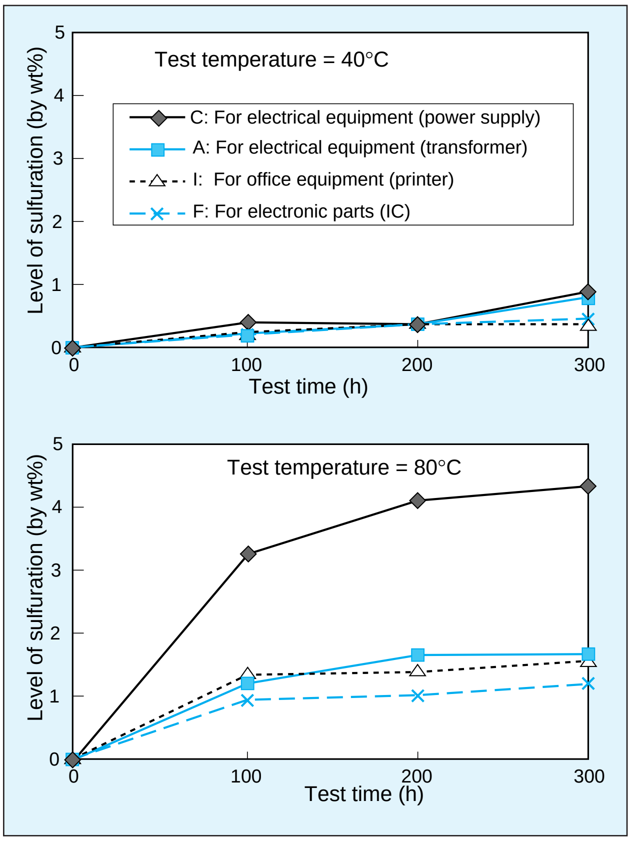


Fig. 3 Level of sulfuration

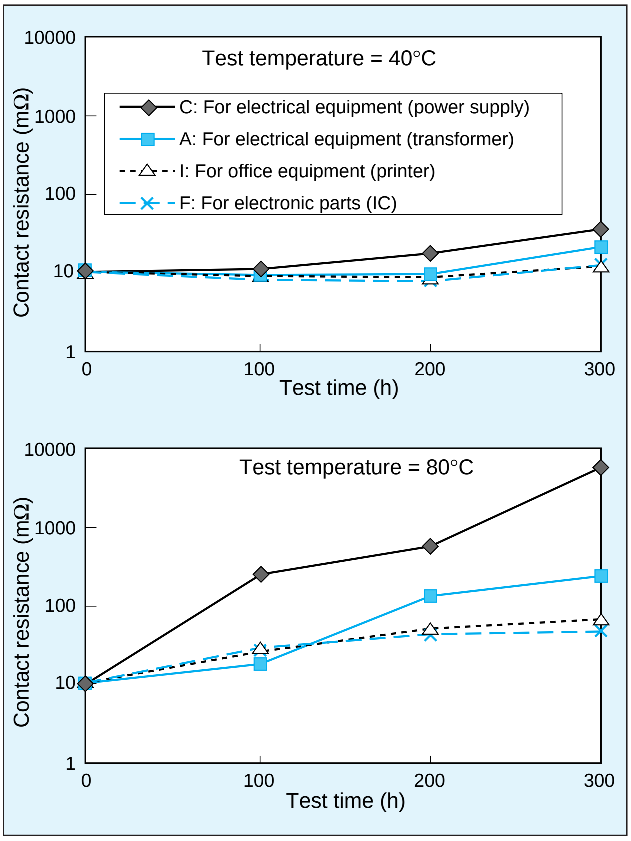


Fig. 4 Contact resistance measurement results

4-4 Solderability testing

To investigate the effect of sulfuration on the condition of the soldered connections, we used solderability testing (wetting balance method) and evaluated zero cross time. Zero cross time indicates the time elapsing from the point at which the test piece is immersed in the solder bath until the force (F) received from the solder bath reaches zero. Fig. 5 shows the principle involved in solderability testing (wetting balance method) and the type chart obtained from the test. Table 5 shows the test conditions.

Table 5 Test conditions for solderability testing

Solder temperature	235°C
Immersion speed	15 mm/sec.
Immersion depth	5 mm
Immersion time	10 sec.
Solder type	H63A (JIS Z 3282)
Flux	Rosin (30% by wt.)

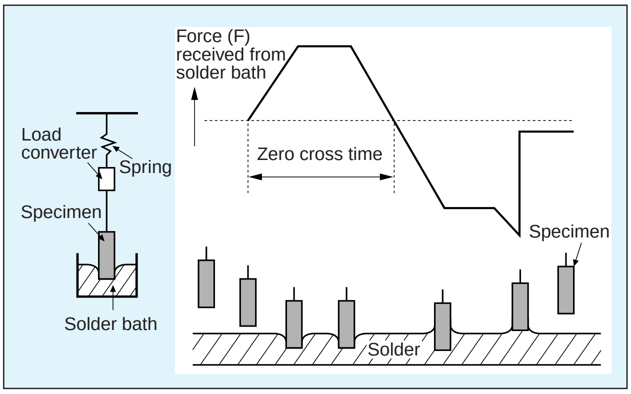


Fig. 5 Principle involved in solderability testing (wetting balance method) and type chart obtained [7]

Fig. 6 shows the results. Smooth wetting was obtained with the test pieces set up without corrugated cardboard, while zero cross time was not even obtained within the 10-second limit for corrugated cardboard types I (for office equipment and printers) and C (for electrical equipment and power supply). Defective appearance was also confirmed for corrugated cardboard types I and C.

These results confirm a deterioration in solder wetting, and indicate that sulfuration has a major impact on the condition of the soldered connections.

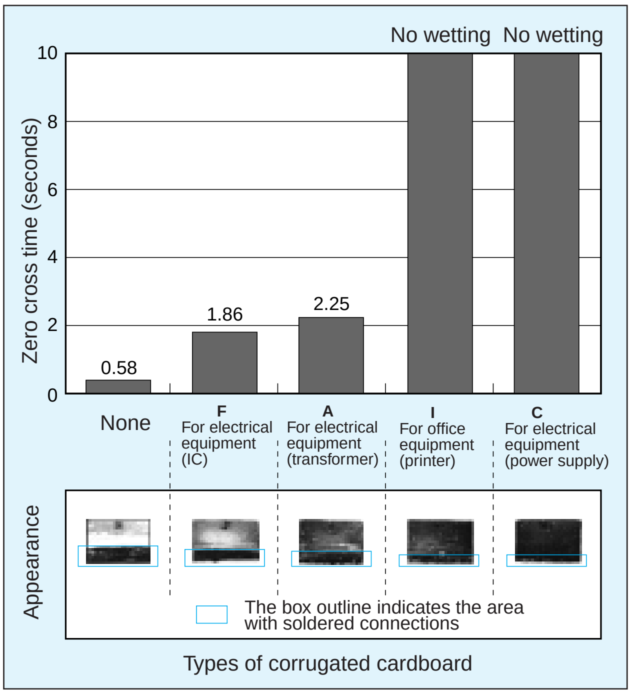


Fig. 6 Test results of solderability testing

5. *Conclusion*

The primary factor in the discoloration and degradation of electrical characteristics in the silver-plated test pieces is the sulfuration resulting from gas emitted from the corrugated cardboard. Sulfuration is controlled by the amount of gas emitted, the temperature conditions, and the set-up conditions. The amount of gas emitted varies with the type of corrugated cardboard, and this variation is determined by the level of residual sulfuric acid ions left by the pulp refinement process. We can also assume that differences in temperature conditions result in changes in the speed of the sulfuration reaction as well as changes in the amount of gas emitted. In addition, differences in set-up conditions produce differences in the amount of exposure to the gas emitted, affecting sulfuration.

Corrugated cardboard is a factor influencing product reliability, and care must be taken in such matters as the type of raw materials used, the temperature during shipping, and the packaging methods used. High humidity is also reported to increase the sulfuration reaction speed, and so the level of ambient humidity during packaging must also be considered[6].

In the future, there should be an increase in demand for corrugated cardboard because of changes in packaging conditions. Because of this, matters such as the relationship with recycled paper, the effect of humidity conditions, the correlation with the actual environment, and the effects on the actual product must be investigated more thoroughly.

6. Acknowledgements

We would like to take this opportunity to express our gratitude to everyone at the fifth sectional meeting of the Union of Japanese Scientists and Engineers reliability development technical research society for their advice on summarizing this report. We would also like to thank Technology Headquarters Department Chief of DDK, Ltd. for providing the specimens as well as advice on test methods.

Definition of terms

*1 EPMA analysis

In this method, an electron beam is aimed at the surface of the specimen, and the characteristic X-rays that are emitted from that place are measured, and the chemical elements of an infinitesimal section of the solid surface are analyzed. The types of chemical elements are determined by the wavelengths, while the concentrations of the chemical elements are determined according to the strength. The EPMA (electron probe micro-analyzer) scans the surface of the specimen, and is able to observe the two-dimensional distribution of the chemical elements.

A non-destructive analysis of infinitesimal areas can be done for all chemical elements above Be, and so this method has a wide range of applications, such as analyzing impurities and minerals in metals, and in the fields of science and biology.

(Source: “Iwanami Physicochemical Dictionary, Fourth Edition”, Iwanami Shoten. 1987)

*2 Wetting balance method

This method is used to investigate changes in the wetting time of specimens. The method detects the vertical surface tensile force for the receptivity of the specimen to solder by immersing the specimen into a bath of molten solder and recording the relationship between receptivity and time. The method is designated in JIS C 0053.

(Source: Tokuzo Kanbe, “Evaluating Plating”, Maki Shoten. 1998)

[Bibliography]

1) Hideo Okamoto, “Causes of Troubles Readily Taking Place at Time of Manufacture, Transportation and Use”, Proceedings of 25th Reliability & Maintainability Symposium, Union of Japanese Scientists and Engineers, pp.311-316, (1995)
2) Corrosion Protection Association Edition, “Introduction to Material Environmental Studies”, Maruzen, pp.177, (1993)
3) Shigeru Nakamura, “Material Control of Ceramic Sensor (Piezoid for Ultrasonic Probe)”, Proceedings of 17th Reliability & Maintainability Symposium, Union of Japanese Scientists and Engineers, pp.243-248, (1987)
4) “Foamed Polystyrene for Packaging”, Nihon Keizai Shimbun,Inc., pp.11, May 27,1998
5) Keiko Shiga et al.,”Study of Evaluation Method of Effects of Sulfur Containing Gas Generated from Rubber Parts Imparted to Silver Contact Parts in Environments Within Sets”, Proceedings of 26th Reliability & Maintainability Symposium, Union of Japanese Scientists and Engineers, pp.157-162, (1996)
6) Hisashi Mine, “Reliability Technology to Make Troubles Zero”, Union of Japanese Scientists and Engineers Publication, pp.150-151, (1990)
7) Electro-plating Research Society, “Physical Properties of Functional Plating Film”, Nikkan Kogyo Shimbun, Ltd.