

Environmental testing and non-destructive failure analysis technology

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This report will discuss failure analysis, and the methods of non-destructive failure analysis in particular, as used to improve quality by analyzing the occurrence of failures and providing feedback to the departments concerned. The report will also include some examples of testing and analysis.

1. Introduction

Most manufacturers use environmental testing and failure analysis to maintain quality and reliability of products and parts.

At the developmental stage, environmental testing is carried out to evaluate prototypes under conditions in which the product will be used, or according to test conditions determined by standards. In addition, when product failures occur in the marketplace, environmental testing is done to perform reproducible experiments as a part of failure analysis.

When defects are reproduced through environmental testing, failure analysis is performed to clarify the cause of the failure and the results are provided as feedback to the design or manufacturing processes involved, and countermeasures are then taken. In this way, environmental testing and failure analysis are crucial measures for maintaining and improving product safety and reliability. This report will specifically focus on concrete instances of failure analysis in the first stage, in which non-destructive inspections are especially common. Fig.1 shows an outline of the product improvement process.

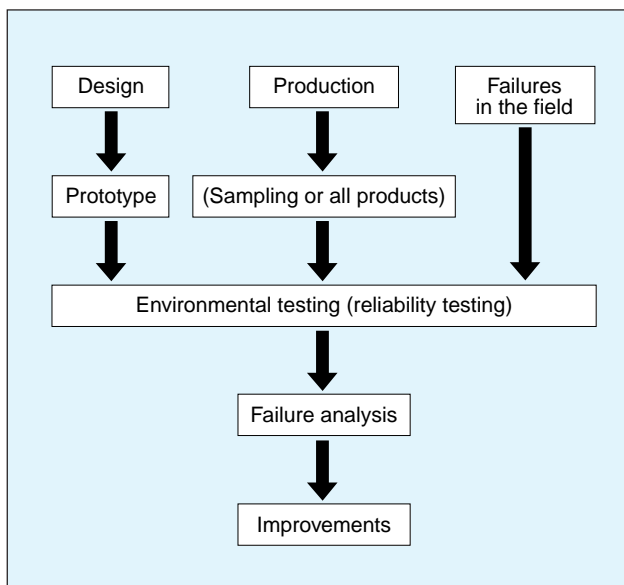


Fig. 1 Requirements for evaluation

2. Approaches of failure analysis

- (1) Even large systems are composed of units and individual subsystems, and those in turn are composed of individual parts, materials, and components that can be analyzed. Failures of these individual parts and materials cause an expanding ripple effect leading to failure of the entire system and causing major accidents. Because of this, reliability is maintained and safety is assured by specifying the causes of these failures and taking countermeasures.
- (2) The bigger the system, the more crucial the problems posed by the interfaces between complex parts and units in which hard sections of individual parts and materials are combined with parts and materials of differing qualities. Accidents due to human contributions such as misuse and incorrect operation also form part of this equation. This can be well understood by looking at the recent Donen accident and airplane accidents.
- (3) In general the cause of failure is said from experience to be due to:
 1. Something that can be handled in design or at the design stage, 80%
 2. Something caused in a production process, 15%
 3. Something due to usage conditions, 5%

Examples of matters that should be handled at the design stage include (a) constructions that lead to mistakes because the items is difficult to use, cannot be operated easily, or has complex operation, (b) constructions with difficult maintenance such as operations or processes that lead to incorrect operation.

Problems at the design stage are more often due to insufficient design investigation (time/frequency, technology, properly qualified personnel) rather than the design itself.

- (4) When failure is very slight, such as only one sample item or one set, product failure analysis looks at whether that failure is likely to have a major impact in the field. Waiting to see whether such failures occur in the field is thought to be too late, and so nowadays quality such as parts, materials, processes, and ease of operation are checked before shipping products to market. A number of examples

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are used to illustrate methods for looking in advance at the possibility of incorrect operation or failure, such as advance analysis (good product analysis) in addition to design investigation. One example is the pre-analysis of the inner conductivity conditions of multi-layer PCBs. (Refer to example 6-1.) Failure analysis considers potential and actual failure mechanisms and performs investigative research to provide corrective measures. These corrective measures can also be applied to other situations. When a failure occurs due to some cause, that cause can be identified as physical, chemical, mechanical, or electrical, or as due to human error. The results can always be explained in terms of the failure being caused according to a particular development.

3. Methods of failure analysis

Failure analysis can be broadly divided into destructive and non-destructive testing. Potential defects and actual failures are identified and confirmed, and electrical, physical, chemical, and human engineering investigations are undertaken. These activities are crucial to creating countermeasures for the causes of failure. Fig. 2 shows the general procedure for failure analysis.

Two methods of locating failure are:

- (1) The overall method {epidemiological method: non-destructive testing}, and
- (2) The individual method {epidemiological method (physical failure method): destructive testing}.

For procedure, less time is lost by taking up the epidemiological method first and the physical failure method later.

An unexpectedly large number of failures can be found with the epidemiological method, but when the epidemiological and epidemiological methods are skillfully combined, reliability can be greatly improved.

- (1) The epidemiological method

This approach uses statistics to explain the degree of failure (e.g., according to time, place of occurrence, market distribution, market location, distribution of usage conditions, distribution of users, by lot, and time differences in manufacturing methods). Even if the reason for this type of failure is not understood, the range encompassing the failures can be narrowed down, and has the know-how to come up with effective countermeasures.

This method can be used by anyone with no need for expensive equipment.

- (2) The epidemiological method (physical failure method)

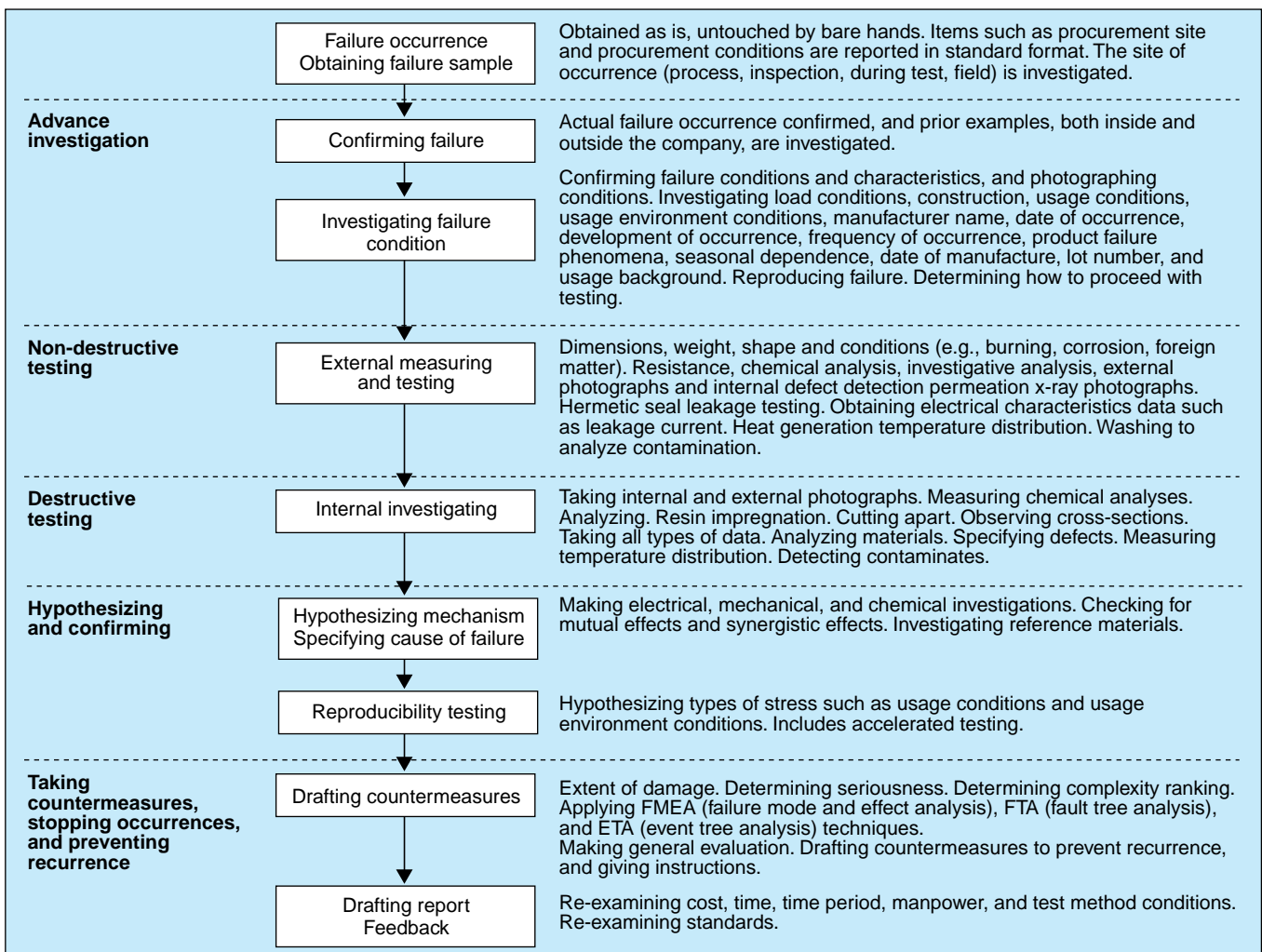


Fig. 2 Example of failure analysis

This approach relies on completely grasping the mechanisms and principles of the failure and narrowing the actual cause to one point. In other words, this method has the know-how to theoretically understand why the failure occurred.

Failure analysis clarifies the cause of failure, understands the failure mechanism, and links these to preventing recurrence of failure.

In failure analysis, it is vital to obtain as much information as possible externally before making a destructive investigation, and normally non-destructive testing is done first. The extent of information obtained from this non-destructive testing will greatly influence later analysis and countermeasures.

When performing failure analysis, the following specific items must be considered.

- 1) Don't analyze with insufficient investigation into factors such as shipping conditions, usage conditions, and usage environmental conditions.
- 2) Don't handle failure samples carelessly.
- 3) When investigating appearance, look at such conditions as dimensions, thickness, weight, shape, bending, color changes, rust, foreign matter adherence, mold, cracking, scratching, cloudiness, scorching, and nicking.
- 4) Since destructive analysis will cause the original shape and conditions to be lost, be sure to take plenty of pictures at the initial stage from every angle, of the piece as a whole, and with enlargements.
- 5) Carefully observe and record each time.
- 6) Since failure analysis uses tools and chemicals, consider worker safety.
- 7) Analyze failure objectively. Don't become convinced that a particular idea must be true.

- 8) Since the human factor is an important cause, consider the background carefully.
- 9) Analysis relies greatly on experience, skill, and power of observation.
- 10) It is dangerous to ignore multiple causes and become convinced of a single cause.
- 11) Don't destroy the object by overloading.
- 12) Compare failed items with good items, and analyze the failures.
- 13) Consider effects from the workers themselves and from jigs, tools, and equipment used.
- 14) Don't throw away the specimens before final results have been attained. Keep them.
- 15) When making judgements, don't simply use the data alone as if it were analysis results.
- 16) Prepare good items from the same lot as the failed items. When the cause of failure is suspected to run across lots, good items must be investigated together across lots.
- 17) As a rule, proceed from the general situation to details to the overall picture. Also, go from external to internal analysis, from peripheral to the object, and from non-destructive to destructive.
- 18) Make full use of such elements as knowledge, experience, and data. Ask for assistance from another specialist.
- 19) In failure analysis, when you have gone on to the next process, you can't go back, so you must observe very carefully at each stage of analysis.

4. Types of non-destructive test equipment

Table 1 shows examples of widely-used non-destructive tests that are low-cost and generally very easy to procure.

Table 1 Examples of non-destructive test equipment

	Name	Cost	Usability	Applications, other
1	Microscope (optical microscope)	Relatively inexpensive	Easy to use	Having a monitor is a plus. Even better if dimensions can be measured on the monitor.
2	Metallurgical microscope	Relatively inexpensive	Easy to use	Same as above
3	Scanning acoustic (ultrasonic) microscope (SAM)	Expensive	Relatively difficult to use	Can be used to see internal defects (e.g., voids, cracking, contamination) and interface conditions
4	Scanning electron microscope	Expensive	Relatively easy to use	High magnification photographs (particularly, above 1000×)
5	Ultrasonic flaw detector (SAT)	Relatively inexpensive	Easy to use	Same as above
6	Soft x-ray apparatus	Expensive	Easy to use	Same as above
7	Ultraviolet flaw detector	Inexpensive	Easy to use	Minute surface cracking, pitting, or flaws
8	Red check	Inexpensive	Easy to use	Same as above
9	Calipers, micrometer	Inexpensive	Easy to use	Checking dimensions and thickness
10	Multimeter	Relatively inexpensive	Easy to use	E.g., watts, resistance, and current
11	Thermography	Expensive	Relatively easy to use	Measuring abnormal surface temperature distribution
12	Magnifying lens (5× or less)	Extremely inexpensive	Easy to use	Overall external observation
13	Magnets, lighters, and so on	Extremely inexpensive	Easy to use	Checking whether magnetic, whether easily flammable, whether heat resistant
14	Precision cross-section cutter	Medium price	Easy to use	Cutting cross sections of materials and parts

(Cont.)

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Name		Cost	Usability	Applications, other
15	Resin filler	Extremely inexpensive	Easy to use	Resin filling of items such as cross-sectioned parts and materials, and for resin filling before cross-sectioning
16	Polisher	Medium price	Easy to use	Polishing resin filled items and inspection items
17	Temperature and humidity chamber	Medium price	Easy to use	Specimen reproducibility testing
18	Ultrasonic cleaner	Comparatively inexpensive	Easy to use	Washing specimens
19	Close-up photography equipment	Medium price	Easy to use	Photographs of specimens from every angle for analysis and evidence
20	Thermocouple thermometer and digital thermometer	Comparatively inexpensive	Easy to use	Measuring temperature and measuring temperature rise

Adding the latest equipment to the above yields dozens of types with prices ranging from several hundred thousand yen to tens of millions of yen.

In internal inspection, equipment such as soft x-ray apparatus is easy to use and has a wide range of applications, and so is widely used. With the acquisition of experience comes the ability to spot specific failure sites and guess the general source of the problem without spending any money.

5. Objectives of environmental tests and the affects of tests

Table 2 shows the relationship between test conditions and the objectives of environmental tests and the affects of test when testing with environmental test equipment.

Table 2 Examples of test conditions and the objectives of environmental tests and the affects of tests

Environmental test		Objectives	Affects	Examples of typical test conditions, other
Temperature	Low temperature resistance	Investigates the low temperature resistance of electronic parts and equipment, and the low temperature storage characteristics. Looks at volume expansion and degradation of characteristics due to freezing, degradation of functions and performance, and mechanical characteristics caused by contraction.	Thermal and mechanical deformation due to expansion and contraction. Promotes softening and brittleness, loss of lubrication characteristics, sealing, cracking, and freezing of liquid portions of the specimen.	From -85°C to room temperature Temperature distribution: from ±0.5 to ±1°C Programmed automatic operation
	High temperature resistance	Investigates temperature-related changes in electronic parts and equipment. When there is an active element, usually it is activated or supplied with electricity at high temperatures and degradation of characteristics is examined. Looks at degradation of lubrication characteristics.	Promotes chemical reactions such as oxidation and diffusion. Expansion, softening, evaporation, oxidation, lowered viscosity cracking, diffusion, and leaking.	From room temperature to 300°C Temperature distribution: ±0.5 to ±1°C Programmed automatic operation
	Temperature cycle	Investigates thermal stress in electronic parts and equipment. Used for screening parts for automotive and aircraft applications. Accelerates usage environments.	Distortion due to expansion and contraction, peeling, cracking, cracking due to liquid evaporation, fatigue, cracks in finished surface, and changes in electrical characteristics due to mechanical displacement.	From -65°C to +150°C Programmed automatic operation
	Thermal shock	Evaluates affects of thermal stress in a short time period by using liquid with a large thermal capacity. Looks at such factors as dimension changes due to differences in coefficients of thermal expansion, and accompanying changes in specimen characteristics and adhesion, evaluation of terminal sealed sections.	Cracking of molded parts, peeling, mechanical deformation, and other factors roughly the same as above.	From -65°C to +150°C Specimen movement, 5 seconds Programmed automatic operation
Humidity	Humidity resistance	Investigates degraded characteristics due to humidity in electronic parts and equipment. Evaluates humidity absorption characteristics of insulation materials, storage, and dry characteristics at low temperatures.	Insulation loss, promotion of corrosion and electrolytes, condensation, expansion, increased leak current, deformation, changes in characteristics, bending	From 85% RH to 95% RH From 10% RH to 40% RH Programmed automatic operation
	Humidity cycle	Acceleration of such factors as condensation and humidity absorption characteristics, and other factors roughly the same as above.	Respiratory effect, dew condensation, freezing, ionic migration.	From 40°C to 80°C From 20% RH to 95%RH

Environmental test	Objectives	Affects	Examples of typical test conditions, other
Dew cycle	Evaluates parts, materials, and equipment for thermal shock resistance while at the same time evaluating changes in characteristics due to condensation occurring concurrent with changes in temperature and humidity.	Ionic migration, corrosion, shorting, insulation defects, and film peeling	From -35°C to +85°C From 60% RH to 90% RH Transfer time, 5 seconds Temperature stabilized, 20 seconds
HAST (PCT)	Accelerated testing of thermal resistance characteristics. Looks at effects of humidity penetration and distribution	IC mold cracking, sealing defects, seal peeling, adhesion characteristics, deformation, corrosion, insulation degradation, cracking, adhesion peeling	125°C at 85% RH (121°C at 100% RH) Both saturated and unsaturated tests possible
Air pressure	Looks at such characteristics as ability of parts, materials, and units to withstand voltage in altitude, vacuums, and high pressure.	Degradation of electrical ability to withstand pressure, sealing (hermetic) defects, degradation of life of contact points, changes in dielectric constants of materials, changes in thermal conductivity, and degradation of insulation.	From 133 Pa to 10 kPa
Salt mist	Accelerated testing of rust and corrosion and anti-corrosion characteristics of leads on electronic parts, and evaluation of coatings, paint films, and platings. Some items can be tested with the CASS (copper accelerated acetic acid salt spray) test. 50°C, 5% saltwater + cupric chloride + glacial acetic acid	Corrosion, rust, insulation degradation, increased contact point resistance, peeling, deformation.	35°C, 5% NaCl 35°C, dry, moist
Weathering test	Looks at degradation of products and materials due to ultraviolet rays and other radiation. (Paint coatings and plastics)	Fading colors, weakness, cracking of high molecular materials, deformation, sealing defects	Equivalent to the sun's rays
Combined environment of organic gases H₂S/SO₂	Accelerated testing to evaluate the corrosion resistive environmental characteristics of leads and metal parts by corrosive gases in atmospheric pollution or emitted from the materials	Effects from such sources as corrosive gases, such as corrosion, rust, insulation degradation, defective contact, wire disconnection, increase in contact resistance	Simple or compound gases SO ₂ , H ₂ S, NO ₂ , Cl From 0.01 ppm to 100 ppm
Acid rain	Looks at the affects of acid rain	Same as above	From 4 to 6 pH
Dust and sand	Looks at degradation of functions and characteristics due to cracking and infiltration-induced contact defects in contact parts and moving parts. Checking hermetic seal, insulation, and corrosion.	Malfunctioning, corrosion, surface wear, clogging, charging, insulation degradation, wear, leakage	Sand, fiber, dust
Ozone	Looks at ozone-induced degradation of characteristics of parts, materials, and products.	Deformation, cracking, oxidation, and weakening of organic materials	From 0.01 to 20 mg/m ³
Vibration	Used for fatigue testing of electronic parts and vibration experiments on products. Also, for the same purposes, looks at structural strength with respect to vibration during shipping and handling of packaged electronic parts, materials, and equipment.	Mechanical looseness, fatigue destruction, wire disconnection, damage due to harmonic vibration, defective socket contact, joint wear, destruction due to harmonics, lead breakage, occurrence of noise and abnormal vibration, cracking	From 2 to 2000 Hz 588 m/s ²
Shock	Looks at mechanical strength due to shock with respect to the same problems noted above.	Same as above	98 to 9806 m/s ² / 1 to 60 ms
Bump	Looks at parts, materials, and products for strength against fatigue received during shipping.	Same as above	392 m/s ² , 6 ms, 196 m/s ² /11 ms
Tensile and bending	Looks at mechanical strength of products and materials in such areas as stretching.	Disconnecting, breaking, deformation, short circuits, stretching	One time or repetitive
Mold	Looks at factors promoting mold and changes in characteristics of materials due to mold	Insulation degradation, short circuits, corrosion, oxidation, erosion, contamination, and degradation of optic system transmissivity	—
Soldering heat resistance	Looks at resistance of electronic parts to solder, strength and heat resistance characteristics, and connectivity.	Solder cracking, looseness of terminal windings, changes in thermal characteristics of parts, softening of insulation materials, deformation	From 200°C to 400°C
Charging, electromagnetic induction, static electricity	Looks at static electricity-induced damage in dry environments, resistance of electronic parts and equipment to static electricity, noise margin resistance characteristics, and relay life evaluation	Radio wave interference, destruction of insulation, adherence of foreign matter, malfunctioning, damage to semiconductors and other parts, operation stoppage, runaway	From 10 kV to 30 kV

HAST: Highly Accelerated Temperature and Stress Test

PCT: Pressure Cooker Test

I.M.: Ionic migration

Photos 1 through 3 show typical environmental test equipment currently in wide use.

(1) Photo 1: HAST (PCT) Chamber

Pressure is raised from a minimum of 1 atmosphere, and specimens are placed in the temperature and humidity conditions of the test area. Parts and materials are evaluated for humidity resistance characteristics and insulation characteristics under highly accelerated conditions. Care must be taken with the maximum permissible temperature of the specimens.



Photo 1 HAST Chamber (Highly Accelerated Stress Test Chamber), product of Tabai Espec

(2) Photo 2: Thermal Shock Chamber

This product is used to effectively evaluate changes in thermal expansion coefficients that are deeply connected to problems in such areas as connections, seal performance, thermal characteristics, inherent stress from manufacturing, compound materials in parts such as molded parts, and mold processing in parts such as ICs. Both liquid phase and gas phase tests are possible, but since liquid phase tests are much more accelerated than gas phase tests, the liquid phase is particularly widely employed for testing parts and materials.



Photo 2 Thermal Shock Chamber (product of Tabai Espec)

(3) Photo 3: Temperature and Humidity Chamber

This is a very widely used tester that maintains constant humidity at both low and high temperatures for all items, and performs combined temperature and humidity (cycle) tests. Industrial water and tap water must not be used in these tests, as they contain contaminants such as minerals and disinfectant chlorine that affect the samples.

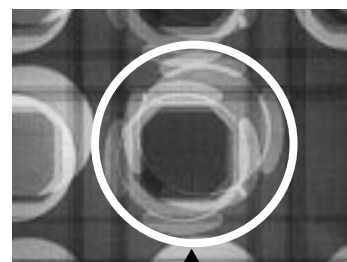


Photo 3 Temperature (& Humidity) Chamber, Platinous K Series (product of Tabai Espec)

6. Examples of non-destructive tests

6-1 Example 1: Analysis of non-defective multi-layered PCBs

Multi-layer printed circuit boards use internal wiring and holes called via to make connections between the layers. (These holes are used exclusively for connecting between layers and are not used for installing parts.) Connections are made through all of the layers using holes called by such terms as “through holes”. If the relative positions of the wiring of each layer is not within tolerance, processing will cause such problems as short circuits and broken wiring, and so these holes must be inspected and screened before processing. Based on the results of inspection using a soft x-ray apparatus, determination is made on whether the relative positions are within tolerance. (Photo 4)



Misalignment in relative position of internal wiring of each layer

Photo 4 Example of defect analysis of multi-layer PCB (photographed with Softex SFX-70)

6-2 Example 2: Broken wire on temperature sensor (production equipment)

The continuity of the internal temperature sensor had to be investigated when it became impossible to control the temperature. The results of an inspection using a soft x-ray apparatus showed a broken connection at a welded joint on the thermocouple sensor tip. (Photo 5)

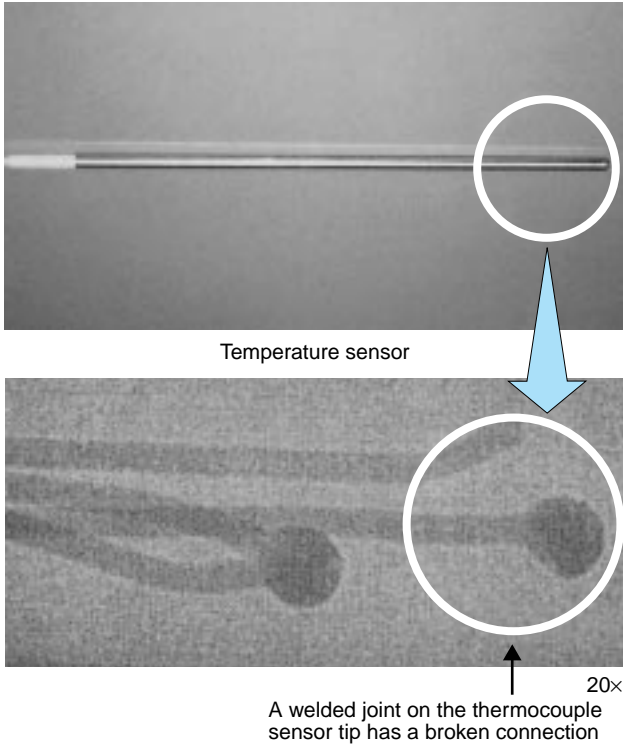


Photo 5 Example showing a broken connection in a temperature sensor (photographed with Softex PR-TEST 100)

6-3 Example 3: IC chip adhesion defect

Internal IC conditions needed to be investigated due to degradation of IC characteristics and mold peeling and cracking. The results of an inspection using a soft x-ray apparatus showed that an air layer (the white section in Photo 6) had developed between the chip and the base due to defective adhesion.

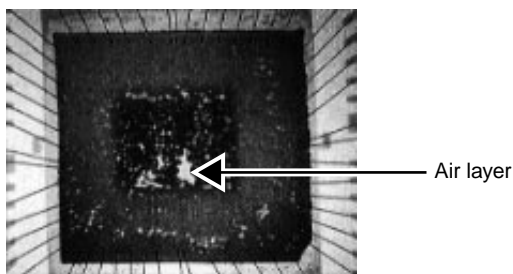


Photo 6 Example of IC chip adhesion defect

6-4 Example 4: Broken connection on sheathed heater (production equipment)

The internal portion of a sheathed heater had to be checked when the temperature inside a chamber would not rise. The results of an investigation using a soft x-ray apparatus showed a broken connection in the heater element. (Photo 7) In addition, an inspection of the external appearance showed corrosion on the stainless steel heater protector tube, with water invading the heater through the corroded section and causing a short resulting in a broken connection.

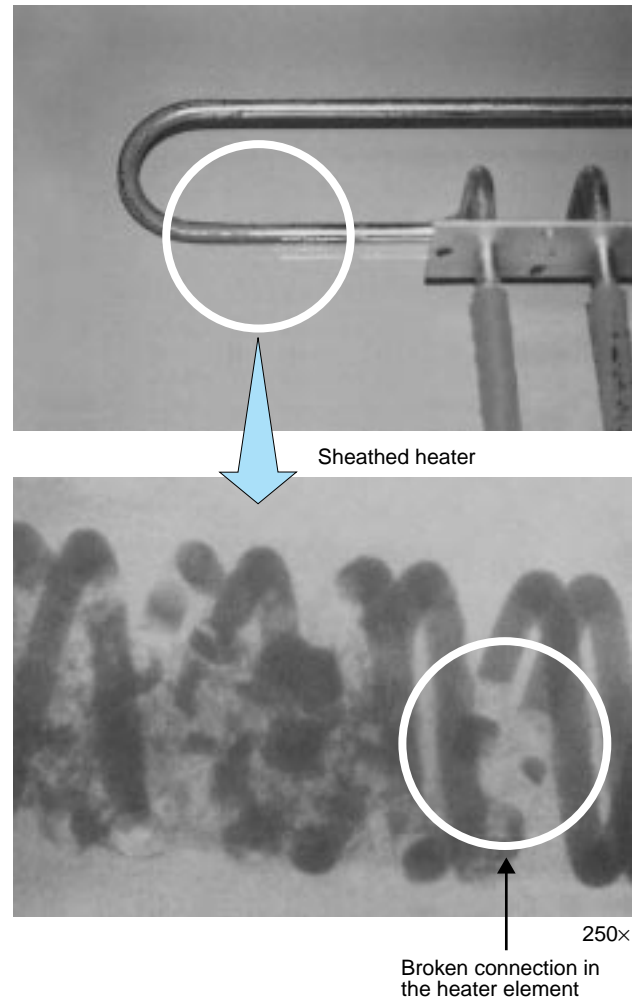


Photo 7 Example of a broken connection in a sheathed heater (photographed using Softex PRO-TEST 100)