Technical Report

Reliability Technology Useful For Sites (Part Two)

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Abstract

The reliability problems that have occurred recently in Japan include examples of problems related to general reliability as specified in IEC 60050, and to bathtub curve-based reliability improvement activities. This report looks at the developments currently taking place at the reliability design, evaluation and assurance activity sites of Japanese manufacturers, and how they differ from developments among Western and Chinese manufacturers. These developments are discussed in terms of reliability technology that is useful for sites, focusing on four specific questions: (1) Will qualitative accelerated testing become established practice in Japan? (2) Have anomalous failure phenomena been eradicated? (3) How are system reliability and IoT technology related? (4) How will Japan respond to reliability technology advances at sites in Western countries and China?

Various quality and reliability problems occurred in 2017 and 2018. The discussion below will present two of these cases in terms of reliability technology. Both incidents will be covered by looking at the current reliability-related developments taking place at Japanese manufacturing sites, and examining possible future developments. This report is the second part of a two-part series.

3. Have Anomalous Failure Phenomena Been Eradicated? (AI and Reliability Technology)

While bathtub curves usually classify failure phenomena into three types (early failures, random failures and wear out failures), there is actually another type known as epidemic failures. Epidemic failures result in very arduous market responses so should ideally be completely eliminated, but unfortunately still occur today. Examining examples of these failures reveals that they are often the result of anomalous failure phenomena.

As shown in Table 3, anomalous failure phenomena are failure phenomena such as migration, whiskers and environmental stress cracking (ESC). They are generated by combinations of specific materials and specific operating environments. Thirty-four phenomena are currently known in areas such as machinery, electronics and materials. Some anomalous failure phenomena have entire books devoted to just one phenomenon. They are failures for which recurrence prevention would normally appear easy.

So with the wealth of examples of past problems that they provide, why have anomalous failure phenomena not been eradicated? While the circumstances may vary by company, the following common issues exist:

(1) Materials about anomalous failure phenomena have only been created in the form of individual past problem case studies, and not been used systematically in the form of databases.

(2) Database compilations of past problem case studies have been created, but response measures for anomalous failure phenomena have not been applied to design standards or updated.

(3) Anomalous failure phenomena are specified in design standards and discussed at design reviews, but mistakes are sometimes made in risk identification (such as by incorrectly assessing occurrence likelihood or giving a passing assessment based on a pass in reliability evaluation testing).

Some of the ways in which manufacturers handle these issues are as follows:

Handling Issue (1): The rise of database software has made it easy to create searchable databases of past problems. At many companies, technical departments or quality assurance departments conduct inspections before holding design reviews or the like.

Handling Issue (2): Table 4 provides an overview of ESC. It is important for each company to incorporate more detailed information than shown here into its specific design standards.

Also important is creating a methodology for updating information, to reflect new developments such as the use of new materials or more highly miniaturized machining technologies.

Handling Issue (3): Although determining how to prevent errors of judgment is a very difficult issue, many companies include reliability evaluations designed to detect anomalous failure phenomena as standard features in their in-house test method standards.

Some companies also create the type of reliability evaluation matrix shown in Table 5 and use it to generate assessment criteria for inspections done before design reviews or the like.

Recent advances in AI technology have enabled some companies to systematize activities such as the three responses above in the form of development/design phase AI tools. In other words, they use AI to assist in technology issue identification at the new product development study phase. Anticipation of anomalous failure phenomena is one item in the process. AI's technical evolution from deep learning to deep generation seems to be providing major benefits.

Table 3 Anomalous failure phenomena and factors generating them

Failures unique to metal materials	Anomalous failure phenomenon name	Related environmental stresses: Atmosphere			Electricity			Physical stress		Related materials: Plastic materials: Thermoplastic resins											Thermosetting resins						Metals						
		Gas	Chemical/solvent	Oil/grease	Electric field (bias)	Power ON/OFF	Arc	Stress	Vibrations/shock	PE (polyethylene)	PET (polyethylene terephthalate)	PP (polypropylene)	PVC (polyvinyl chloride)	PS (polystyrene)	AS (AS resin)	ABS (ABS resin)	PA (polyamide (nylon resin))	PC (polycarbonate)	POM (polyacetal)	PTFE (polytetrafluoroethylene)	PF (phenol resin)	MF (melamine resin)	UF (urea resin)	EP (epoxy resin)	UP (unsaturated polyester resin)	Silicone resin	Gold	Silver	Copper	Iron	Nickel	Zinc	Aluminum
Electrolytic corrosion	Electrolytic corrosion				○												△				△	△					←						Combination
	Aluminum electrolytic corrosion				◎																												◉
Migration	Ion migration				◎																○						○	◎	○				
	Electromigration				◉																												○
Stress corrosion cracking	Alkaline cracking		◉					○																									
	Chloride cracking		◉					○																									
	Ammonia cracking	◉						△													△												
Whiskers	True whiskers							△																								○	
	Non-true whiskers	◎																										◎	○				
Failures in intermetallic compounds	Purple plague																										◉	←				→	◉
	Tin joining																										○	○	○		○		
CAFs (conductive anodic filaments)					◉																								○				
Cathodic oxidation					◉																												
Dissimilar metal bonding																					△						←						Combination
Dezincification corrosion																																	

Table 4 Example overview of ESC (environmental stress cracking)

Phenomenon	Description	Materials prone to occurrence	Analysis/evaluation methods	Solutions
Oil cracking	Generated in combination with residual and external stresses when a substance such as an oil/grease activator or PVC plasticizer seeps into plastic.	Styrene compounds (polystyrene, ABS, AS, acrylic)	• Heat resistance test: Evaluation for 500 to 1,000 hours at temperatures of 20 to 30°C higher than the operating temperature. • Immersion test: Crack generation is checked after immersing the sample in a solvent or other substance it is expected to make contact with. • Methods effective as practical tests, done by applying solvents to samples while they are subjected to constant stresses. Samples are usually evaluated at temperatures of up to 40°C, for up to 240 hours.	• Stress elimination/dispersal • Processing at 120°C for 6 hours (in case of heat-treated polycarbonate) • Discontinuing use of solvents and oils causing cracks • Using various tests to adequately evaluate affinities with resins
Solvent crazing	Generated in combination with residual and external stresses when a solvent such as alcohol or toluene is absorbed by plastic, causing swelling.	Polystyrene, ABS, polycarbonate, acrylic, PPO		
Season cracks	Cracks generated over time when large residual or external stresses are applied.	Polycarbonate, polyethylene, polystyrene, ABS, AS, acrylic, phenol		

Table 5 Reliability evaluation matrix overview

Product features a. Part/material types and characteristics b. Structure c. Manufacturing conditions/method d. Operating conditions/ environment	1. Predict the types of failures that are likely to occur given the product's features.	Example 1: When the parts used include ICs of CMOS and TTL types → CMOS ICs are prone to electrostatic breakdown. Example 2: Variable resistor operating conditions include both AC and DC application → Migration is prone to occur during DC application.
	Failure mode (Or guaranteed characteristics)	Evaluation conditions a. Official standards b. User standards c. In-house standards
Evaluation items a. Test items b. Analysis items	2. Determine what evaluation items should be used to detect the failure mode. Example 3: IC wire breaks → Can be detected using stresses such as thermal shocks/vibrations. Thermal shocks are best. Example 4: Variable resistor plastic cracks → Can be detected by tests of resistance to heat, chemicals, oils or the like. Apply as required by the conditions.	3. Use the applicable standard as a reference to determine the specific conditions to use for each evaluation item. Example 5: High-temperature load life of square chip resistors → All standards use rated load at 70°C. But some use 125°C for accelerated evaluation. Example 6: High-temperature load life of ICs 60°C/95% RH 85°C/85% RH

4. How Are System Reliability and IoT Technology Related?

Today's passenger planes send key fuselage parameter information to the ground (the maintenance department at the arrival airport) while in flight. This technology enables major reductions in maintenance work time after arrival and greatly helps improve the standard of maintenance inspections. It has reportedly been further perfected on the Boeing 787. This example could be considered a system product (aircraft) application designed to use IoT technology (sensors, communication technology and data analysis technology) to improve general reliability as specified in IEC 60050.

General reliability improvements attained by combining system products with IoT technologies in this way are actually a very high-growth area, as demonstrated by the following everyday examples:

(1) Luxury vehicles send operation and vehicle information to the dealer over communication lines. The information is useful in maintenance inspections and the like.
(Use of this technology was reportedly pioneered by Tesla, and it has now been released in brands such as Mercedes and Lexus.)

(2) Communication of elevator operation information has for many years enabled comprehensive online/on-time management by maintenance/inspection companies. But now research is being done to determine whether elevator surveillance camera information can be analyzed by AI to be useful for security management in the building.

Examples such as these show how advances that combine IoT and AI technologies are making solid improvements in the general reliability of system products. As illustrated by Table 1 in the first part of this report, system products involve manufacturers of lower-level materials, devices, modules and set products. So what effects do they have?

The discussion below looks at the example of autonomous driving technology, an area of fierce development competition among manufacturers. The conditions in this area are as follows:

● System manufacturers (carmakers and others): How to assess information from cameras and sensors (AI technology) is one of the key development points. But as described in Section 4, extensive time is needed to identify operation information when using deep learning alone. Developers have therefore recently been attempting to evolve AI toward deep generation. (Additionally, deep learning was responsible for the AlphaGo algorithm that amazed the world in 2015 and 2016 by beating a world-class player of the Japanese board game *go*. The same company has already developed an algorithm incorporating deep generation. Developed in 2017, the algorithm is named AlphaZero.)

● Module/device manufacturers: The biggest issue is determining how much to improve the performance and reliability assurance of cameras and sensors. As a well known example, environmental resistance performance is a vexing problem for reliability assurance. Manufacturers don't know the degree to which functions that are completely problem-free under sunny or cloudy conditions should be guaranteed under snowy or drizzly conditions.(Should conditions equivalent to South Pole blizzards (decadal events) be considered?) Carrying out the reliability evaluations needed requires market testing, and raises reliability tester issues such as whether bench testers can recreate various snowfall conditions.

Applications made possible by combining system products with IoT technologies should advance rapidly in many different areas in future, and will likely have a major impact on reliability technology among peripheral to lower-level manufacturers.

5. How Will Japan Respond to Reliability Technology Advances at Sites in Western Countries and China?

Despite some variations, international scientific associations in the field of reliability have continued to carry out activities. But what is the current state of reliability technology at manufacturer sites in Western countries and China?

I have received quality control and reliability education in the West, the ASEAN region, China and elsewhere, and have noticed the following region/country-specific features:

(1) There are few region-to-region differences among the particulars or application of techniques used in the field of quality control.
But some regional features exist. For example, discussion over the need for zero defects is particularly prevalent in China, and many companies in North America use Six Sigma techniques.

(2) Among reliability technologies, the greatest differences are found between Japan and the EU. The EU conceives of reliability in terms of dependability, whereas Japan has always approached the field purely in terms of reliability.
My sense is that something close to the former interpretation is favored by most companies in China, and something close to the latter by most companies in the ASEAN region (with its large Japanese corporate presence).

Table 6 and Figure 6 are excerpts of materials on reliability evaluation approaches and practices that are used in reliability education overseas. While topics such as the logic of reliability technology tools are not discussed, reliability engineers from around the world increasingly ask questions when the topic turns to application method approaches (as shown by these examples). For example, there is not much discussion about Items 1, 2, 5, 7, 8 or 10 among the ten pointers on reliability shown in Table 6. But there is always discussion on approaches and application methods for the other items. Figure 6 illustrates Item 6 in more detail. The topic of so-called worst-sample reliability testing often elicits questions such as whether the reliability assurance range for the product specifications is 4.5 sigma as defined by Six Sigma. How about your company? (Do you recommend starting with worst-sample testing? And if so, what is the logical basis for doing so?)

Table 6 Reliability educational material example 1: Ten pointers for reliability evaluations

1. **Be faithful to the operating environment/conditions.**
2. **Tailor the evaluation to the failure mechanism prediction.**
3. **Tailor the evaluation to the new product development steps.**
4. **Evaluate back upstream.**
5. **Identify the life and destruct limit.**
6. **Evaluate a sample that takes variation into account.**
7. **Always disassemble and analyze the product.**
8. **Accelerate the evaluation to reach a conclusion rapidly.**
9. **Pay attention to what has been changed.**
10. **Evaluate by focusing on anomalous failure phenomena.**

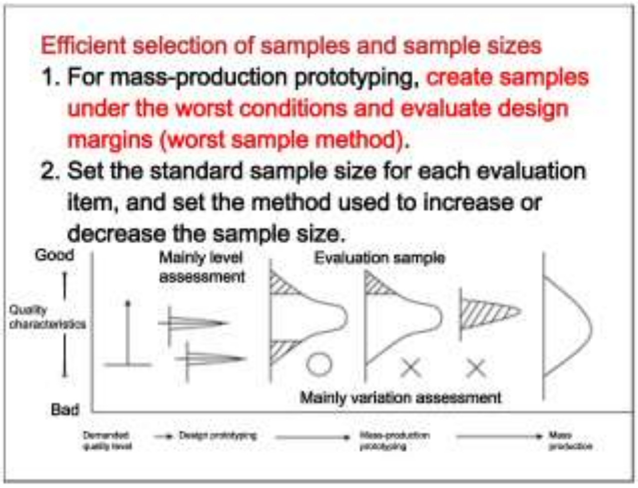

Figure 6 Additional information for Item 6 in ten pointers for reliability evaluations

But as shown in Table 7, nearly no discussion is elicited by educational content such as market failure prediction methods (such as predicting market failure rates 5 and 10 years out when two years have elapsed), since the content pertains to statistical and reliability/physical areas. Instead, the time ends with just a technical Q&A session.

Japan's development leadership in a number of areas has been eclipsed by global development efforts that encompass major manufacturers from Western countries and China. Competition over this global development is currently intensifying and should continue to do so into the near future. The areas in question include automotive technologies such as EVs, autonomous vehicles and flying cars, along with aerospace technologies such as reusable launch vehicles and space station administration. Reliability is a priority for all these areas and (as shown by the example above), phases from development through implementation might reveal differences in approaches to reliability in future.

Reliability studies for products in new segments are increasingly being done through temporary use in the actual market of specific regions only. China leads the world in the size and speed of new product trials, followed in diminishing order by the US, the EU and finally Japan. This ranking will clearly have a major impact on reliability technology development in the years ahead, which is a concern for Japanese companies.

Table 7 Reliability educational material example 2: Market failure prediction methods

Market Quality: Failure Rate Prediction (Using Three Failure Prediction Techniques Below)

	Failure prediction technique	Description
1	Prediction by market data analysis (such as Weibull analysis)	Prediction is done using data analysis based on the number of problem occurrences for various usage periods in the market, and the applicable product shipment counts.
2	Prediction by simulation testing	Test items and conditions are set based on the failure phenomena and failure modes of the problem products. Simulation testing is carried out using products for the applicable period, and prediction is done by data analysis based on the occurrence rate and shipment count.
3	Prediction from failure occurrence mechanism	If the failure phenomenon and occurrence mechanism are understood, the effects of stresses on failures are determined. Prediction is done by data analysis based on the occurrence ratio and shipment count for each stress.

6. Conclusion

This two-part report in the current and previous issue of *Test Navi Report* has discussed bathtub curve-based reliability issues by discussing four questions from the perspective of sites.

While reliability design and assurance issues vary by manufacturer, I imagine that some of the issues raised by the four questions discussed here will be applicable to your company. I hope that these site reliability issues will continue to be discussed at scientific conferences and symposia in the field of reliability, and that the reliability technology expertise of Japanese manufacturers can continue to lead the world.