Automotive

Yamaha Revs Your Heart

An Evaluation of Delamination of Power Modules using the MicReD T3Ster®

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Yamaha Motor Co. Limited is a Japanese manufacturer of engines for a diverse set of industry sectors including motorcycles and other motorized products such as scooters, electrically power assisted bicycles, sail boats, personal watercraft, utility boats, fishing boats, outboard motors, 4-wheel ATVs, recreational off-highway vehicles, racing kart engines, golf cars, multi-purpose engines, generators, water pumps, snowmobiles, small-sized snow throwers, automobile engines, surface mounters, intelligent machinery, industrial-use unmanned helicopters, and electrical power units for wheelchairs. Now a major multinational company, it was established in 1955 and has its headquarters in Shizuoka, while employing nearly 54,000 people worldwide and turning over annual revenues of $US14Bn/yr.

> *"The use of T3Ster in our delamination stress tests of solder joints therefore allows us to quantify the process of solder crack development more sensitively and quicker than any other methods, and to track the relationship between the change in thermal resistance, ⊿Rth, of the sample under test relative to the number of test cycles it experiences."*

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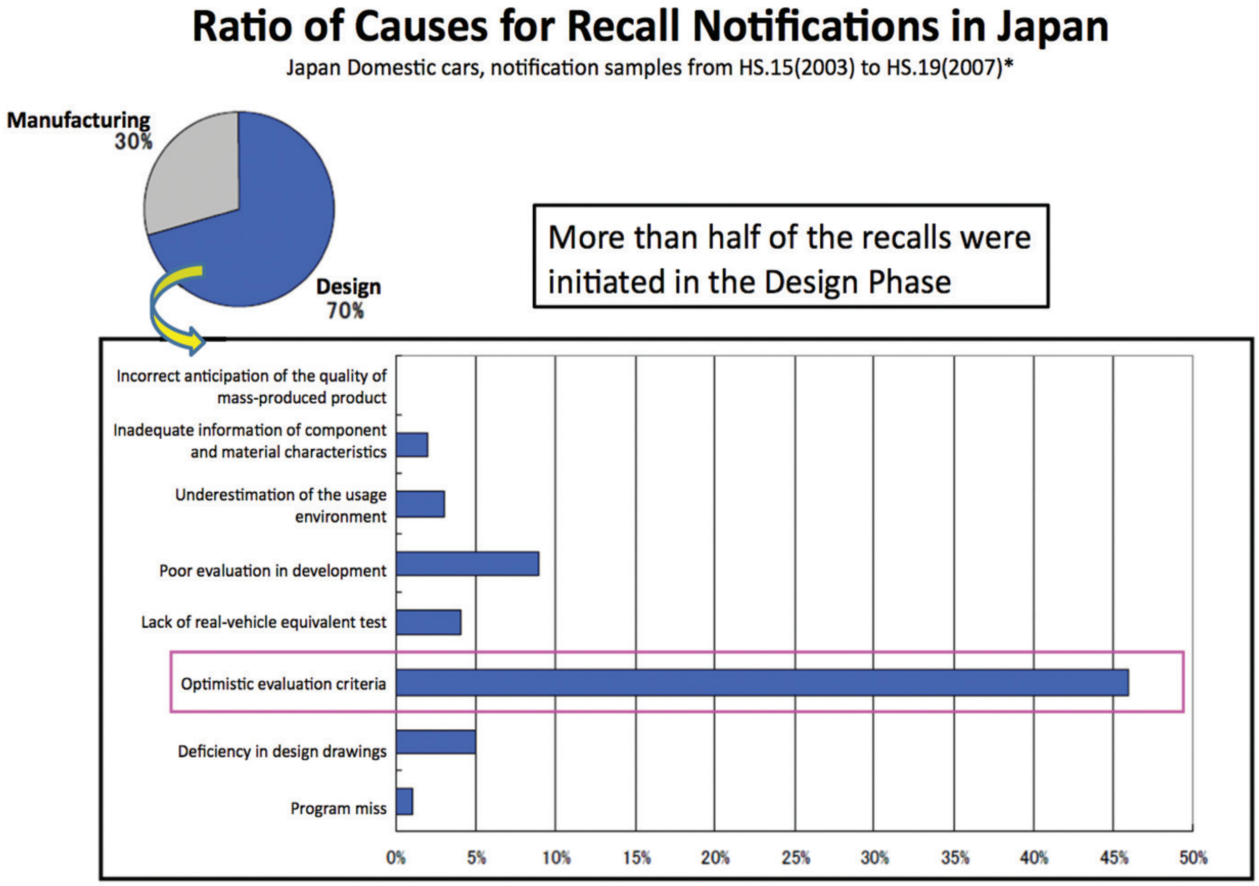

Figure 1. The Importance of Evaluating Product Reliability for Automobiles - the need for good Testing Criteria to Verify Design Approaches
Source: HS.20(2008) Analysis result of recall notification (Japanese Ministry of Land, Infrastructure, Transport and Tourism

Key to Yamaha's success over the years has been its laser focus on reducing market complaints in its products, hitting defined reliability targets in a cost effective way, and ultimately continuously shortening its new product development times. In the Research & Development Section, Technology Center of Yamaha Motor in particular, there is a recognized need to accelerate testing to speed up general product development and, in particular, electronic control units attached to Yamaha engines and motors. Such PCB electronics can be exposed to high thermal loads during normal operation especially with Yamaha's high power density products.

Reliability of Yamaha's products is paramount and temperature related issues due to electrical, mechanical, and thermal effects are critical. Indeed, as Figure 1 illustrates, most domestic automobile recalls in Japan are due to design related errors rather than problems in manufacturing, and the biggest source of design problems can be seen to be due to the lack of a good physical test method to validate and benchmark design approaches.

In general, the use of electronic devices in engine control systems (ECS), safety systems and telecommunications is increasing rapidly across the world (Reference 1). When compared to consumer electronics, electronic devices for motor vehicles and engines are often exposed to much more severe environments such as higher temperatures, fluctuating temperatures, intense vibration, and high humidity. Furthermore, considering the longer product life expected for a motor vehicle, these electronic devices are expected to have a higher level of reliability and be something that lasts over a long period.

The normal method used for attaching electronic components like resistors and capacitors to printed circuit boards for ECS electronic devices is soldering. Generally, circuit boards and the electronic components mounted on them have different coefficients of thermal expansion, and the difference in the amount of expansion and contraction they undergo causes thermal stress in the solder connecting them (Figure 2). These in turn will result in "solder cracks" forming within the joint and eventually solder breakage which leads to defective electrical conductivity and ultimately product failure. Thermal stress on wire bonding could cause lethal crack, too. Thermal fatigue characteristics of solder and PCB reliability can be evaluated by means of temperature cycling tests that subject the

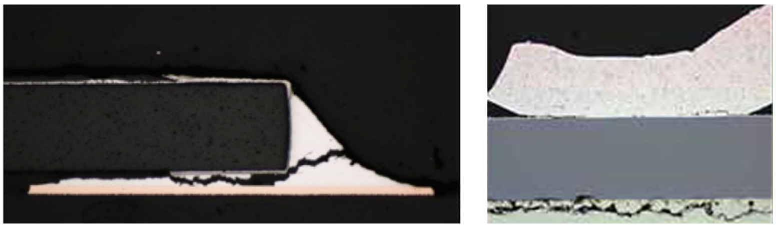

Figure 2. Example of Solder Cracking and Wire Bonding Crack

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solder to repetitive cycles of high and low temperature conditions, but even these accelerated test cycles can require several months in a laboratory. Hence, there is a need to shorten development time and reduce the number of rework tasks involved, reducing cost by optimizing product quality up front of prototyping is also an important issue, and these two factors increased the need for the manufacturer to devise technology that can estimate the thermal fatigue life of solder joints and the detection of the formation of solder cracks rapidly.

In response to these needs, Yamaha has been developing reliability methods and technologies for evaluating solder joints in electronic devices inside its products focused on temperature fluctuations in particular. In addition, we wanted to accelerate our test methods for detecting and preventing the delamination of power modules for our products to speed up our overall product development efforts. By targeting the reliability of solder joints we needed to target thermal reliability the most because thermal stresses are the biggest source of failure.

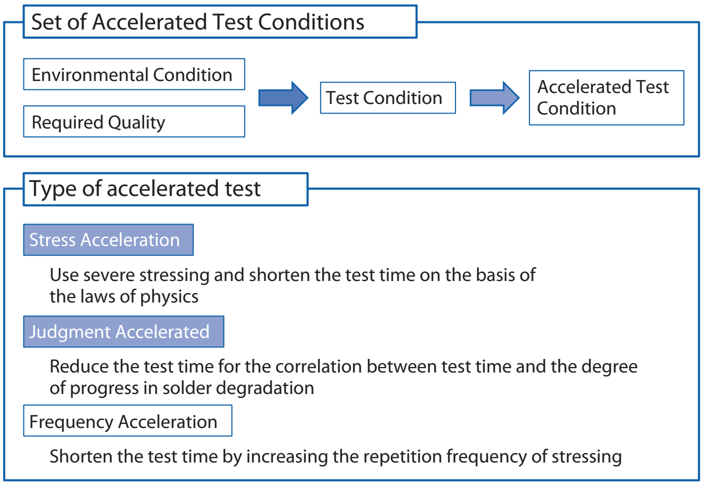
In this article we describe how we devised an accelerated solder joints thermal benchmarking test methodology that's validated to:

- Reduce market complaint in our products
- Help define a Reliability Target that is cost effective
- Shorten overall Product Development Time.

Our novel approach involved three strands to accelerating our Delamination Testing Methodology (see Figure 3) which we call:

1) **Stress Acceleration** conditions (due to high temperature, high pressure etc.),
2) **Judgment Acceleration** conditions (i.e. making our judgment on the delamination quicker with the minimum amount of test information possible), and
3) **Frequency Acceleration** conditions (i.e. more sample cycling tests).

Frequency Acceleration was the easiest to control (Figure 3) as it is part of standard test methodologies. For Stress Acceleration we devised a proprietary Arrhenius type mathematical expression that correlates the relationship between the lifetime of a solder being cycled with its operating temperature range which I will not go into detail here. Our Judgment Acceleration condition relies on a wide set of in-house tests on a wide range of Power Module devices that allows us to produce a database of Yamaha measurements from which we can extrapolate from our existing performance data so we don't have to do a wide range of measurements for a new Power Module test scenario. The approaches to Judgment Acceleration and Stress Acceleration will be dealt with here.


Set of Accelerated Test Conditions

Environmental Condition

Required Quality

Test Condition

Accelerated Test Condition

Type of accelerated test

Stress Acceleration

Use severe stressing and shorten the test time on the basis of the laws of physics

Judgment Accelerated

Reduce the test time for the correlation between test time and the degree of progress in solder degradation

Frequency Acceleration

Shorten the test time by increasing the repetition frequency of stressing

Figure 3. Yamaha Methodology for Accelerating Test Conditions of Solder Delamination

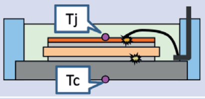
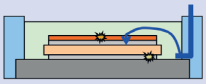
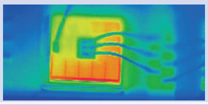
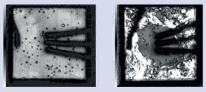
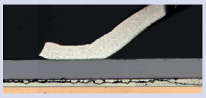
Evaluation Method	Advantages	Disadvantages	
Thermocouple Measurement (Tj - Tc temperature)	• Non-destructive inspection	• Heat leakage • Indirect evaluation	
Electrical Resistance Measurement (ON resistance)	• Non-destructive inspection • Realtime evaluation process	• Indirect evaluation	
Thermal Video Camera (Radiation thermometer)	• Surface temperature distribution measurement	• Destructive inspection • Indirect evaluation	
Ultrasonic Microscopy (Flaw detection)	• Crack visualization	• Destructive inspection • Measurement site limited	
Cut it Open (Cross-sectional observation)	• Crack visualization	• Destructive inspection • Fragment evaluation	

Figure 4. Solder Degradation Test Evaluation Methods including the Pros and Cons of each.

The most important elemental technology for successful Judgment Acceleration and Stress Acceleration test is how to evaluate the degradation. We have been looking for an effective method to detect degradation. If we examine the approaches available to us to do stress tests and track delamination of solder joints (Figure 4), each has its advantages and disadvantages. We wanted our stress test validation approach for the evaluation of cracks in the targeted solder joints to be a non-destructive measurement technique that was not only fast, very accurate, close to real time, but also able to avoid intrusive measurement equipment errors. This led us to T3Ster® thermal transient testing equipment from Mentor Graphics to meet our test criteria.

We've considered a typical Power Module resistance measurement (Figure 5) during the cycling test which can track the relationship between ON Resistance (by monitoring V_{ds} when the chip is powered) to crack formation, so that crack development over time can be seen. However, it was not sensitive enough to detect the initial solder delamination progress. So we tried T3Ster's structure function methodology (Figure 6). This non-destructive measurement technique is very valuable in determining the formation of delamination cracking not only from the beginning, but also its propagation and ultimately die-attach failure.

The use of T3Ster in our delamination stress tests of solder joints therefore allows us to quantify the process of solder crack development more sensitively and quicker than any other methods. The structure function produced by T3Ster allows us to track the relationship between the changes

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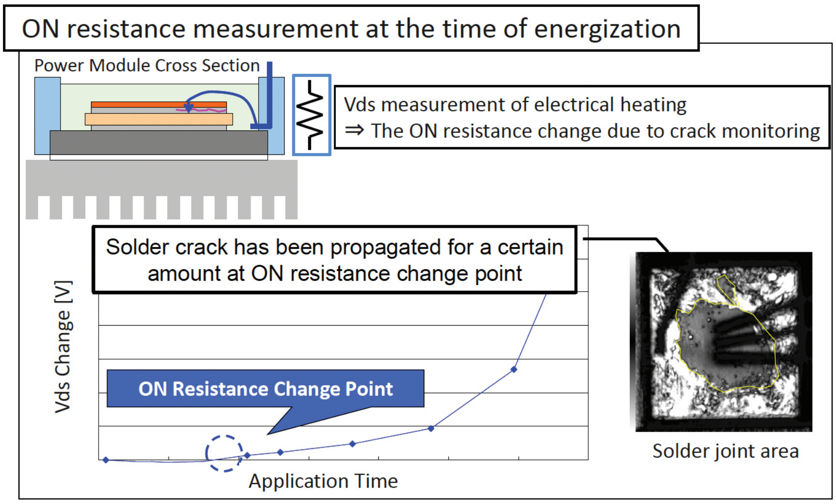


Figure 5. Relationship between Solder crack over time and ON resistance, which was not sensitive enough to detect the initial solder delamination

in thermal resistance, ⊿Rth, of the sample under test relative to the number of test cycles it experiences (Figure 7).
By using T3Ster, Judgement Acceleration can be achieved since we now have the ability to detect the initial crack, and we know the speed of degradation after the initial crack. This in turn allows us to shorten our overall development time for such stress tests and T3Ster also provides valuable diagnostic data on what's happening to thermal paths inside each layer of the sample being tested.

When we were developing the technologies for Stress Acceleration, the dominant factors influencing lifetime were considered to be junction temperature (Tj). The relation between ΔTj and lifetime was investigated while Tj(min) was fixed to 25°C as the first step. The result showed lifetime is a function of ΔTj and if we put field application environment and experiment environment into consideration, it was able to determine the acceleration factor and decide acceleration test configurations. The second step was to study the influence of Tj(min), we set Tj(min)>25°C then repeated step one. From the test data we found, higher Tj(min) led to shorter lifetime but slope of "lifetime vs. ΔTj" does not change (Figure 8). This result demonstrated that acceleration test configurations are independent of Tj(min) and the same test configuration can be applied to any Tj(min). Furthermore, by clarifying the influence of thermal stress period, chip size and category of solder, we discovered more accurate Stress Acceleration test configurations.
In conclusion, T3Ster has proven to be very powerful to Yamaha and helps us to accelerate our reliability test methodology.

Reference:

1. "Estimating the Thermal Fatigue Life of Lead-free Solder Joints" by T. Ima, Yamaha Motor Technical Review, pp43 – 47, Number 49, 2013
http://bit.ly/1oj1lvU

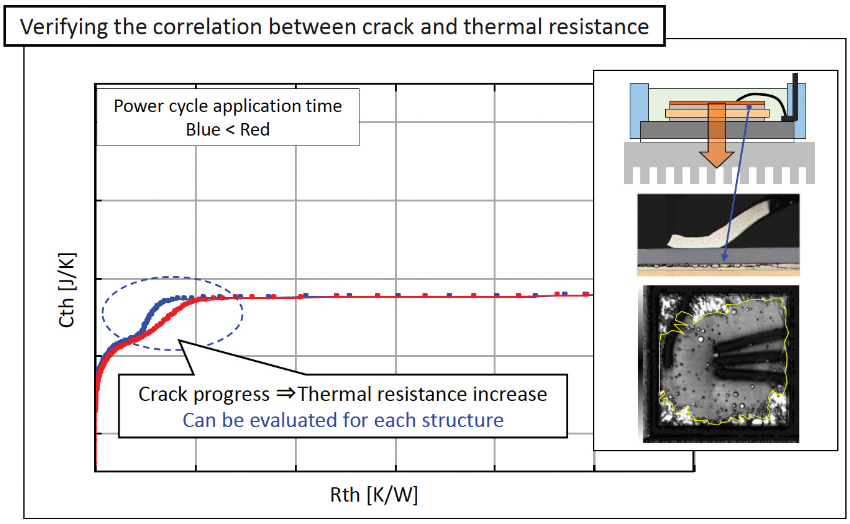


Figure 6. Structure Function thermal resistance increase from T3Ster can detect the initial solder delamination

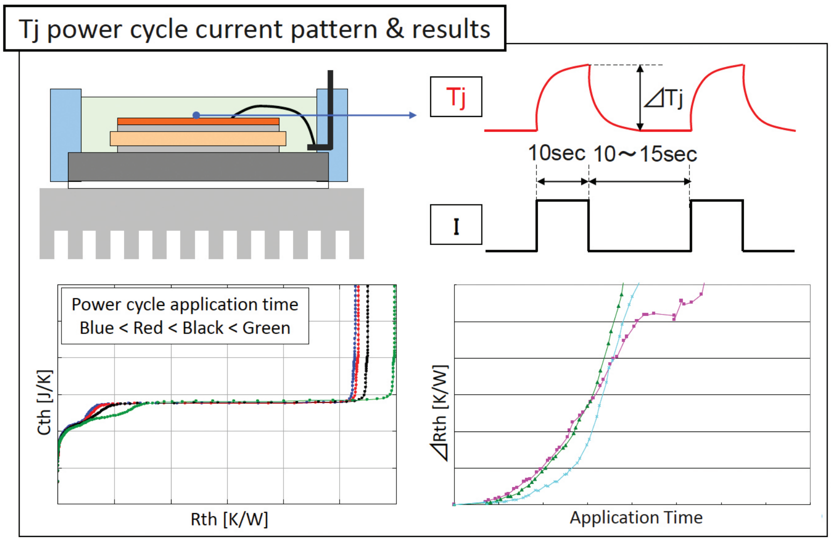
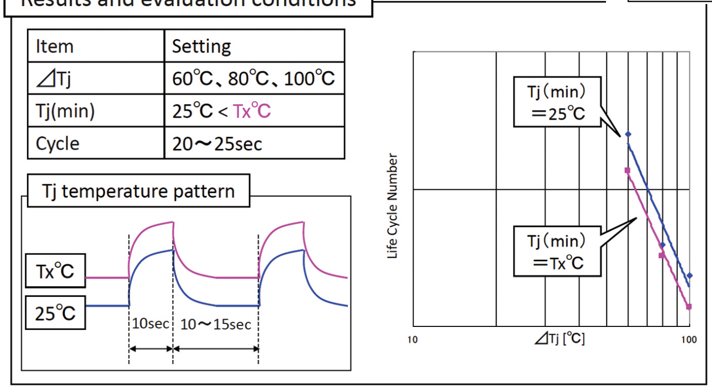


Figure 7. Typical Lifecycle evaluation in junction temperature during a T3Ster power cycle test and the resultant change in thermal resistance, ⊿Rth, versus number of test cycles.

Results and evaluation conditions



Item	Setting
⊿Tj	60℃、80℃、100℃
Tj(min)	25℃ < Tx℃
Cycle	20～25sec

Figure 8. Solder Degradation - Impact on sample lifetime of different Tj power cycle test conditions in T3Ster.

Mentor Graphics
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