Siemens Digital Industries Software

Evaluating delamination of power modules using Simcenter T3STER

Yamaha develops test methodology to evaluate reliability of solder joints

Executive summary

Thermal fatigue characteristics of solder and PCB reliability can be evaluated by means of temperature cycling tests that subject the solder to repetitive cycles of high and low temperature conditions, but these test cycles can require several months in a laboratory. Yamaha Motor Company sought to accelerate test methods for detecting and preventing the delamination of power modules products to speed up overall product development. The company developed a methodology using the Simcenter™ T3STER™ test solution to quantify the process of solder crack development more sensitively and more quickly than any other methods.

Tetsuya Ima
System Research Group, Fundamental Technology Research Division
Research and Development Section, Technology Center
Yamaha Motor Co. Ltd.

Background

Yamaha Motor Company Limited is a Japanese manufacturer of engines for a diverse set of industry sectors including motorcycles, scooters, electrically power-assisted bicycles, sailboats, personal watercraft, utility boats, fishing boats, outboard motors, four-wheel all-terrain vehicles (ATVs), recreational off-highway vehicles, racing carts, golf carts, 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, Yamaha Motor Co. was established in 1955 and has its headquarters in Shizuoka. The company employs nearly 54,000 people worldwide and has revenue of $14 billion annually.

The key to Yamaha's success over the years has been its laser focus on reducing market complaints for its products, hitting defined reliability targets in a cost-effective way and ultimately continuously reducing its new product development times. In the Research and Development Section of the Technology Center of Yamaha Motor, 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. 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 is the lack of good physical test methods to validate and benchmark design approaches.

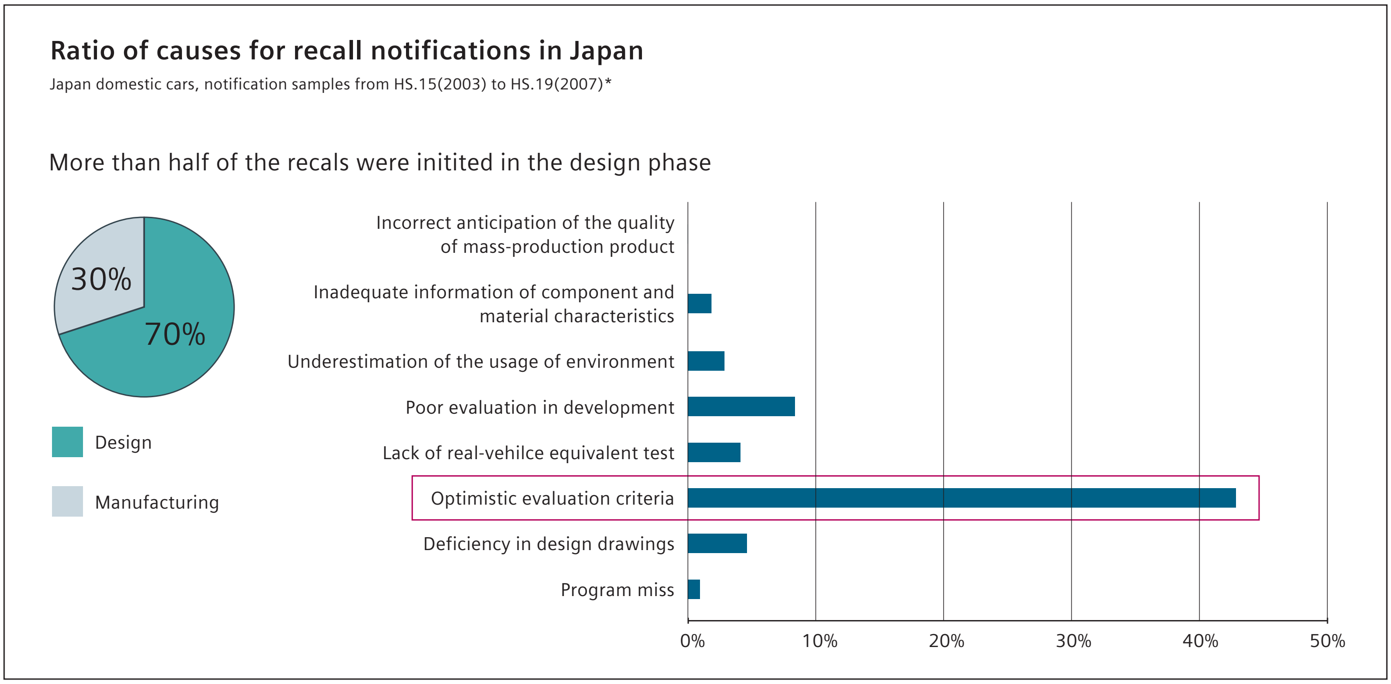


Figure 1: The importance of evaluating product reliability for automobiles - the need for good testing criteria to verify design approaches (Source: HS.20-2008 analysis result of recall notification, Japanese Ministry of Land, Infrastructure, Transport and Tourism).

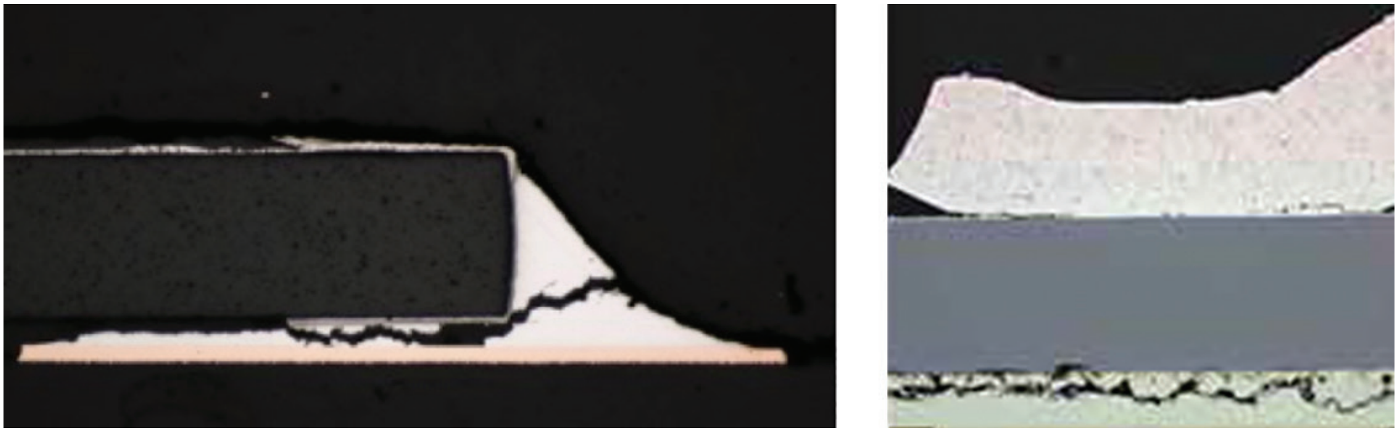


Figure 2: Example of solder cracking and wire bonding crack.

In general, the use of electronic devices in engine control systems (ECS), safety systems and telecommunications is increasing rapidly across the world.[1] 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, lasting over a long period.

The normal method 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). This results in solder cracks forming within the joint and eventually solder breakage that leads to defective electrical conductivity and ultimately product failure.

Thermal stress on wire bonding can also cause lethal cracks. Thermal fatigue characteristics of solder and PCB reliability can be evaluated by means of temperature cycling tests that subject the 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 before prototyping. These two factors increase the need for manufacturers to devise technology that can estimate the thermal fatigue life of solder joints and detect 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 in its products, focusing on temperature fluctuations in particular. In addition, Yamaha wanted to accelerate test methods for detecting and preventing the delamination of power modules for its products to speed up overall product development. By targeting the reliability of solder joints, Yamaha needed to focus primarily on thermal reliability because thermal stresses are the biggest source of failure.

Developing a thermal test methodology

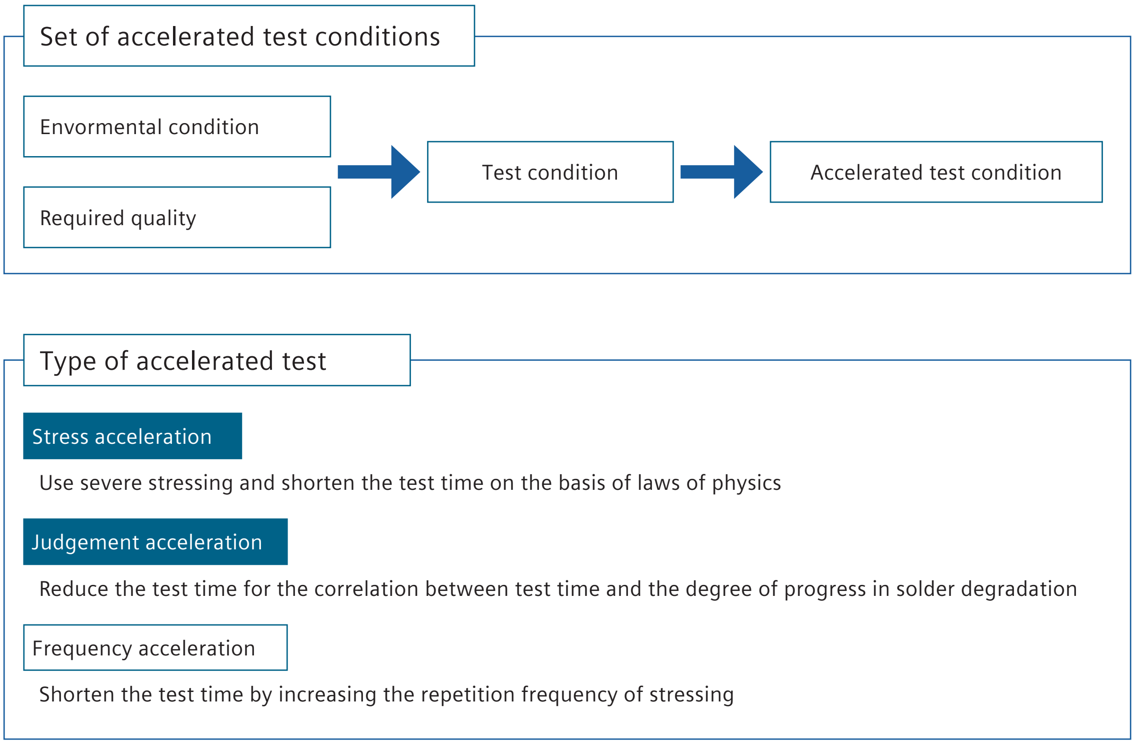


Figure 3: Yamaha methodology for accelerating test conditions of solder delamination.

Yamaha devised an accelerated solder joint thermal benchmarking test methodology that is validated to:

- Reduce market complaints about products
- Help define a reliability target that is cost-effective
- Shorten overall product development time

Yamaha's novel approach involved three strands to accelerate the delamination testing methodology (see figure 3):

1. Stress acceleration conditions (due to high temperature, high pressure etc.)
2. Judgment acceleration conditions (making judgments on the delamination faster with the minimum amount of test information possible
3. Frequency acceleration conditions (more sample cycling tests)

Frequency acceleration was the easiest to control, as it is part of standard test methodologies. For stress acceleration Yamaha devised a proprietary Arrhenius-type mathematical expression that correlates the relationship between the lifetime of a solder being cycled with its operating temperature range. The judgment acceleration condition relies on a wide set of in-house tests on a wide range of power module devices that produces a database of Yamaha measurements from which the company extrapolates from existing performance data, reducing the need for a wide range of measurements for new power module test scenarios. The approaches to judgment acceleration and stress acceleration are the focus of this paper.

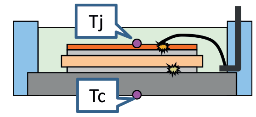
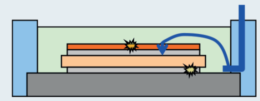
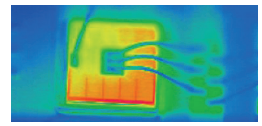
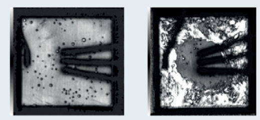
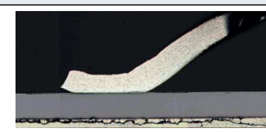
Evaluation method	Advantages	Disadvantages	
Thermocouple measurement (Tj - Tc temperature)	Nondestructive inspection	Heat leakage Indirect evaluation	
Electrical resistance measurement (ON resistance)	Nondestructive inspection Real-time evaluation process	Indirect evaluation	
Thermal video camera (radiation 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 with advantages and disadvantages.

The most important elemental technology for successful judgment acceleration and stress acceleration testing is how to evaluate the degradation. Yamaha was searching for an effective method to detect degradation. The approaches available to Yamaha for performing stress tests and tracking delamination of solder joints have their advantages and disadvantages (figure 4). Yamaha wanted the stress test validation for the evaluation of cracks in the solder joints to be a nondestructive measurement technique that was not only fast, very accurate, and close to real-time, but also to avoid intrusive measurement equipment errors. This led Yamaha to Simcenter T3Ster thermal transient testing equipment from Siemens Digital Industries Software to meet the test criteria.

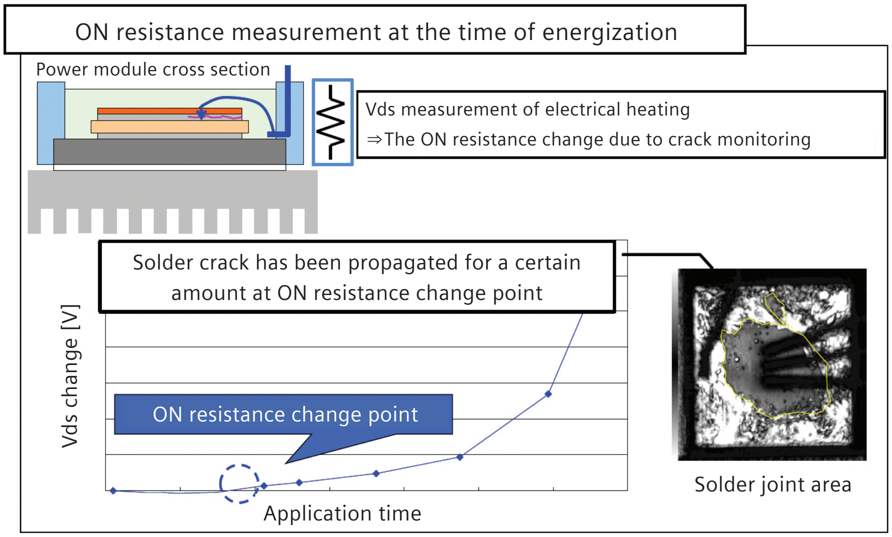


Figure 5: Relationship between solder crack over time and ON resistance, which was not sensitive enough to detect the initial solder delamination

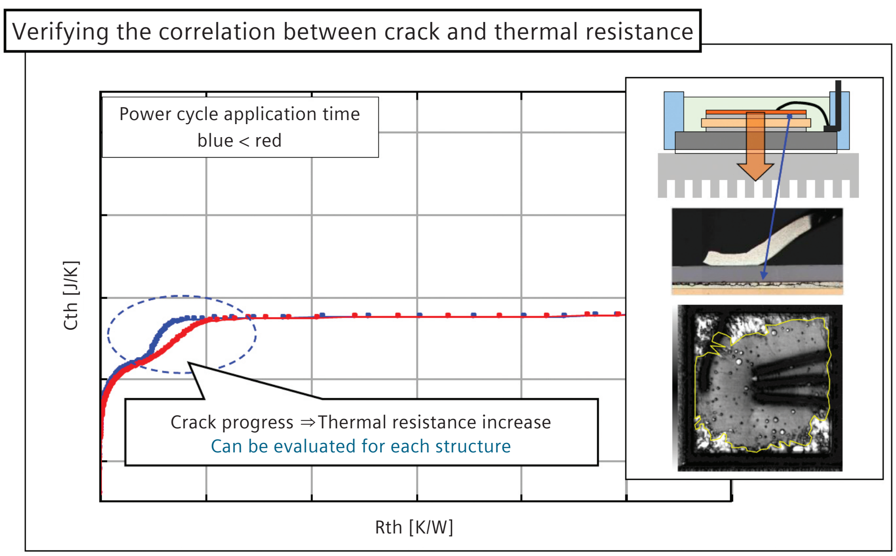


Figure 6. Structure function thermal resistance increase from Simcenter T3STER can detect the initial solder delamination

Yamaha considered a typical power module resistance measurement (figure 5) during the cycling test that can track the relationship between ON resistance (by monitoring Vds 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 Yamaha tried the structure function methodology of Simcenter T3STER (figure 6). This nondestructive 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.

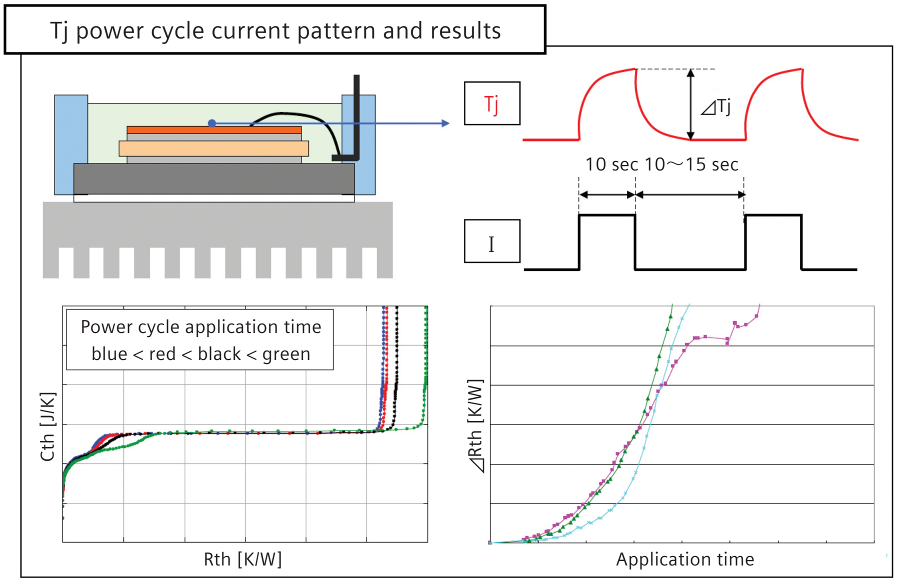


Figure 7: Typical lifecycle evaluation in junction temperature during a Simcenter T3STER power cycle test and the resultant change in thermal resistance (ΔRth), versus number of test cycles.

The use of Simcenter T3STER in delamination stress tests of solder joints therefore allowed Yamaha to quantify the process of solder crack development more sensitively and quicker than any other methods. The structure function produced by Simcenter T3STER allows Yamaha to track the relationship between the changes in thermal resistance (ΔRth) of the sample under test relative to the number of test cycles it experiences (figure 7).

By using Simcenter T3STER, judgement acceleration can be achieved since the company now has the ability to detect the initial crack and identify the speed of degradation after the initial crack. This in turn allows Yamaha to shorten overall development time for such stress tests. Simcenter T3STER also provides valuable diagnostic data on what is happening to thermal paths inside each layer of the sample being tested.

When Yamaha was 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 the field application environment and experiment

"The use of Simcenter T3STER in our delamination stress tests of solder joints allows us to quantify the process of solder crack development more sensitively and more quickly than any other methods, and to track the relationship between the change in thermal resistance of the sample under test relative to the number of test cycles it experiences."

Tetsuya Ima
System Research Group, Fundamental Technology Research Division
Research & Development Section, Technology Center
Yamaha Motor Co. Ltd.

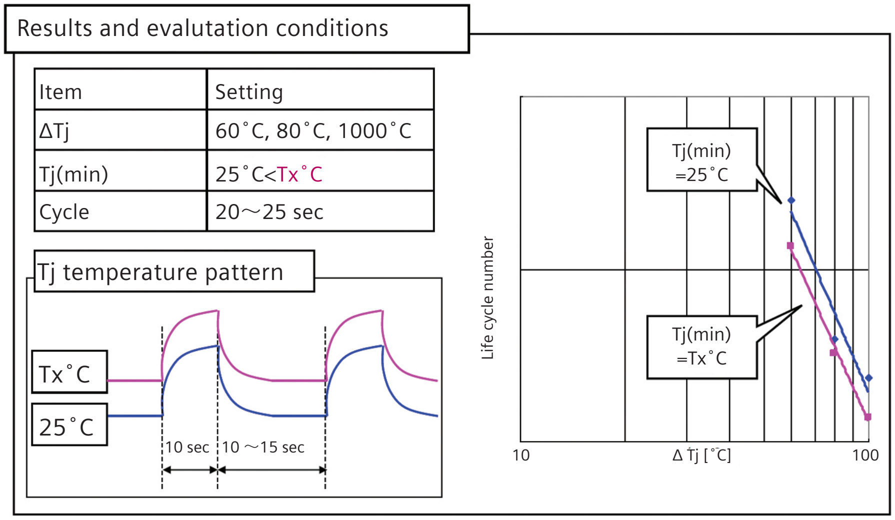


Figure 8: Solder degradation - impact on sample lifetime of different Tj power cycle test conditions in Simcenter T3STER.

environment are considered, it is possible to determine the acceleration factor and specify acceleration test configurations. The second step was to study the influence of Tj(min): Tj(min) was set at >25°C, then step one was repeated. The test data indicated that higher Tj(min) led to shorter lifetime but the slope of lifetime versus 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, Yamaha discovered more accurate stress acceleration test configurations.

In conclusion, Simcenter T3STER has proven to be very powerful to Yamaha and helps accelerate its reliability test methodology.

References

1. “Estimating the Thermal Fatigue Life of Lead-free Solder Joints” by T. Ima, Yamaha Motor Technical Review pp. 43 – 47, Number 49, 2013

Siemens Digital Industries Software

Headquarters
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 972 987 3000

Americas
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 314 264 8499

Europe
Stephenson House
Sir William Siemens Square
Frimley, Camberley
Surrey, GU16 8QD
+44 (0) 1276 413200

Asia-Pacific
Unit 901-902, 9/F
Tower B, Manulife Financial Centre
223-231 Wai Yip Street, Kwun Tong
Kowloon, Hong Kong
+852 2230 3333

About Siemens Digital Industries Software

Siemens Digital Industries Software, a business unit of Siemens Digital Industries, is a leading global provider of software solutions to drive the digital transformation of industry, creating new opportunities for manufacturers to realize innovation. With headquarters in Plano, Texas, and over 140,000 customers worldwide, we work with companies of all sizes to transform the way ideas come to life, the way products are realized, and the way products and assets in operation are used and understood. For more information on our products and services, visit siemens.com/plm.

siemens.com/plm

78294-C3 8/19 Y