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Protective coatings of electronics under harsh thermal shock

J. Pippola [*], T. Marttila, L. Frisk

Department of Electrical Engineering, Tampere University of Technology, Finland

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ABSTRACT

Industrial electronics devices commonly encounter harsh environmental conditions during their operational lifetime. To protect the electronics from conditions like humidity and contaminants, protective moulding and coating materials can be used. However, the behaviour of materials in harsh environments and their effect on the reliability of electronics in industrial products has been studied only very little. Moreover, the changes in the parameters of several commonly used materials under various conditions remain largely unknown. In this paper the effect of the protective coating and moulding materials on product level reliability of an electronics device was studied under thermal shock test. In addition, the change in the mechanical properties of the materials under test conditions was studied. The conditions of the test used were relatively harsh with extreme temperatures of −40 °C and +125 °C. The samples used in the study were commercial electronics devices designed for use in harsh conditions. The protective materials studied included silicone based conformal coating, polyurethane based moulding material, and silicone based moulding material. Moreover, a comparison test with no protective materials was conducted. The results showed that conformal coating and polyurethane based moulding material markedly decreased the times to failures of the devices. On the other hand, silicone based moulding seemed to slightly improve the reliability of the devices.

1. Introduction

The constantly increasing role of electronics in various industrial applications has resulted in increased demands on the reliability of electronics under harsh environmental conditions. The environments the electronics in industrial applications are exposed to vary from clean and stable environments to hazardous areas with very high concentrations of corrosive pollutants, making the protection of the electronics essential. In addition to the corrosive elements, devices are often exposed to humidity and temperature variations during their life cycles.

Polymers are commonly used to protect electronic components against thermal and mechanical stresses. Materials like epoxy, polyurethane, silicone, acryl and polyimide are the best known materials for such protection. Their main function is to protect electronic components against humidity and pollutants, and to increase the thermomechanical stability of the electronics. The variety of protective materials is wide and, with additive ingredients such as fillers and elastomers, the properties of the materials can be tuned even more [1,2]. In addition to the processing parameters, important material parameters which need to be considered when materials are selected are coefficient of thermal expansion (CTE), elastic modulus, resistivity to harmful chemicals and radiation, and the level of moisture absorption [1]. Additionally, the adhesion between a substrate and the protective material is critical and should be high enough to withstand the stresses during operational conditions. Furthermore, the thermal conductivity and electrical properties of the protective material need to be considered to ensure adequate resistivity and dissipation of heat. The lifetime of industrial electronics may be very long. It is common that many material parameters change in long-term exposure to harsh conditions. For example the mechanical parameters of epoxy mould have been found to change in long-term exposure to high temperatures [3,4] and thermal cycling [5]. Moreover, water absorption has been found to cause epoxy to swell [6]. Although epoxy has been widely studied, only little is known about the long-term changes in the parameters of other moulding materials i.e. polyurethane (PU) and silicone under various conditions, even though they may be critical for the long-term reliability of a product.

In this study the effect of protective materials on the reliability of an electronics device was studied using a thermal shock test. The materials used in the study were silicone based conformal coating, polyurethane based semi-rigid moulding material, and more elastic, silicone based moulding material. In addition to the reliability of the devices tested, material parameter changes during

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[*] Corresponding author.

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testing were also studied. Thermo mechanical analysis (TMA) was used to study the CTEs of the materials before and after testing.

2. Experimental

2.1. Test samples

In Fig. 1 a schematic picture of the test sample used in the study is presented. The sample was a part of a commercial electronics device. The device was designed for use in harsh conditions in various industrial applications. The temperature limits for the operating conditions for the whole device were −40 °C and +85 °C. However, in this study only the electronic parts of the device were studied, i.e. the cover of the device was not used during testing.

The electronics parts of the device included two printed circuit boards (PCB). The PCBs were mounted on top of each other and the electrical contact between the PCBs was made with a pin header connector. The device was powered using low voltage direct current of 4–20 mA, which was also used as a communication link between the device and its monitoring system. The integrated circuit (IC) for the communication as well as voltage regulation electronics was located in the top PCB while the bottom PCB contained, for example, the main microcontroller. The voltage regulation electronics on the top PCB included components which may produce heat under operation. As the device was designed also to fulfill the regulations for hazardous areas, the most heat generating components had to be moulded under protective material to spread the heat for a higher volume resulting in lower surface temperature of the device. Therefore half of the top PCB was covered with a mould, as can be seen in Fig. 1. The other parts of the device were covered with conformal coating. In this study polyurethane based material and a silicone based alternative with two different mould techniques were studied.

2.2. Test series

Table 1 presents the test series of the study. Six different test setups were studied. The first test setup 1-BARE consisted of eight samples without any protective materials. In the second test series 2-PU+CC polyurethane moulding as well as the conformal coating was used. To study the effect of the materials separately, the third series, 3-CC, consisted of eight samples, to which only conformal coating was applied, and the fourth series, 4-PU, eight samples to which only polyurethane mould was applied. The conformal coating in test series 3-CC was not applied to the space reserved for the moulding. In test series 4-PU the mould was only applied to the reserved area and other areas were left bare. To study alternative material for the semi-rigid polyurethane mould silicone rubber was used as the moulding material in test series 5-SR1 and 6-SR2. In series 5-SR1 silicone rubber was applied only to the area used with the PU mould. In test series 6-SR2 the whole top PCB was moulded with silicone. No conformal coating was used in either of the silicone moulded test series.

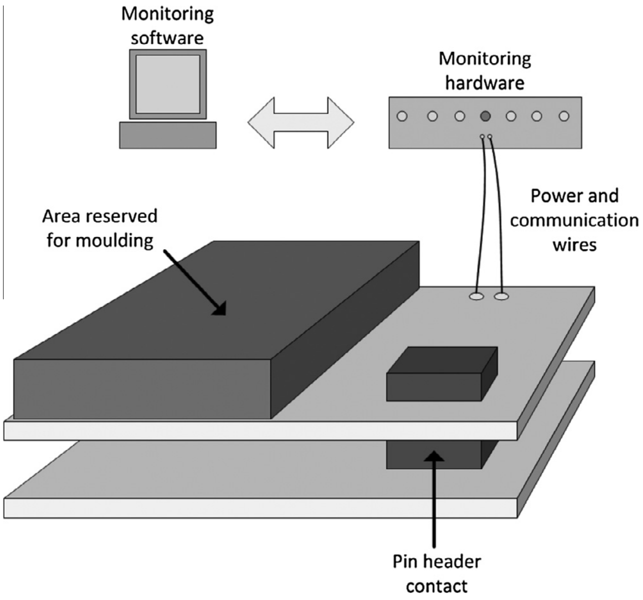

Fig. 1. Drawing of the test sample and monitoring system used in the study.

2.3. Test methods and failure criteria

The accelerated environmental test method used in this study was a thermal shock test according to standard JESD22-A104D [7]. The lower temperature extreme of the test was −40 °C and the upper +125 °C. One test cycle lasted for 30 min. The change time between the extremes was approximately 2 min and the dwell time 13 min. The test was conducted in 100–250 cycle periods until all devices failed.

During testing the devices were monitored with special equipment designed specifically for these devices. A two-wire communication link was provided between the monitoring equipment outside the test chamber and the device inside the chamber. Computer software was used to detect if a communication between the monitoring hardware and the device had failed. If the communication loss was due to device failure the communication breakdown time was used as the failure time of the device. The failed devices were removed from the test chamber. However, the devices could be removed only during test breaks, which were every 100–250 cycles, and therefore cycles to failure were not the same as test times in the thermal shock test. Because of this, if more than one failure occurred in a device, the order of failures could not be determined.

3. Results

The results from testing are shown in Figs. 2 and 3, in which the cumulative distribution functions (CDF) for the test series are presented. The CDF presents cumulative failure percent as the function of the time to failure, or, as in this case, cycles to failure.

Fig. 2 presents the results from test series 1-BARE, 2-PU+CC, 3-CC, 4-PU, and 5-SR1. These results show that the failures in test series 2-PU+CC, 3-CC, 4-PU, and 5-SR1 started almost at the same time. However, after the first failure 5-SR1 had clearly better reliability than the other test lots. Test series 2-PU+CC had the lowest reliability and the failures in this test lot occurred quickly after the first failure. In both test series 3-CC and 4-PU failures occurred more slowly than in series 2-PU+CC. However, the differences between the test series were small, which indicated that both conformal coating and polyurethane mould were causing the failures in test series 2-PU+CC. In test series 1-BARE the failures started later than in the other test lots with conformal coating or polyurethane mould, which further confirmed that they both were critical from the reliability point of view.

Fig. 3 presents the results from test series 1-BARE and both test series with the silicone rubber mould, i.e., series 5-SR1 and 6-SR2. The samples in test series 6-SR2, in which the whole top PCB of the sample was moulded with silicone rubber, showed the highest reliability in the thermal shock. However, the temperature measurement from the interface of the PCB and mould revealed that the temperature of the top PCB did not reach the extreme values