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Lifetime and failure analysis of perovskite-based ceramic NTC thermistors by thermal cycling and abrasion combined stress

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ABSTRACT

A perovskite-based ceramic NTC (negative temperature coefficient) thermistor was developed. A ceramic NTC thermistor was used for sensing the temperature of the heated roller from a laser printer. FMEA (failure mode and effect analysis) was applied to find the effective stress factor on the reliability of the sensor. System failure caused by the malfunction of a thermistor was studied. Possible failure modes, effective stresses that can lead to shortened lifetimes, and potential weak points of the thermistor were analyzed. The combined stress of thermal cycling and abrasion was found to be the most important factor among the listed effective stresses. The temperature profile of the thermal cycle was designed by taking into account the actual operating conditions, and an accelerated lifetime testing machine for estimating operational lifetimes was developed for the profile with a roller rotation. The lifetime of thermistor was estimated from the duration frequency of the thermal cycle using a lifetime testing machine with a roller rotation.

Introduction

A ceramic NTC (negative temperature coefficient) thermistor is widely used for measuring temperature. Various types of thermistor elements are selected depending on the application by taking into consideration important factors such as space restrictions, response time, or temperature range, from a low temperature (~100 °C) to high temperature (~1000 °C) [1]. Thermistors can be exposed to a variety of environmental stresses. Therefore, designing an accelerated test method to find the weak points of the component is important to identify which stress factors lead to component failure based on actual operating conditions [2]. In a laser printer, NTC thermistors detect the surface temperature, which can exceed 250 °C, of the heated roller inside the cartridge as shown in Fig. 1 [3]. This information is then sent to the micro-controller. If the NTC thermistor has failed, the printer cannot properly control the temperature of the roller and can cause a fire. Therefore, NTC thermistors in laser printers are one of the important components that are directly related to PL (product liability) [4]. The purpose of this study is to characterize the potential weak points of a ceramic NTC thermistor, and to predict the component's lifetime in a laser printer.

2. Simplified FMEA for accelerated life test stress

Effective stresses need to be identified to find a potential weak point of ceramic NTC thermistors and to accurately predict the lifetime of a sensor. Through simplified FMEA (failure mode and effect analysis), potential effective stresses are identified in Table 1 [5–10]. The most common effective stresses that can cause sensor failure are thermal cycling and abrasion stress caused by the mechanical rotation of the roller. In a laser printer, the sensor undergoes both thermal cycling and abrasive stressing because it is attached to the heated roller to measure the surface temperature. Therefore, an accelerated lifetime test should contain both types of stresses.

3. Ceramic NTC thermistor based on perovskite developed

A contact type temperature sensor of ceramic NTC thermistor is composed of a bulk ceramic, electrode, lead frame, molding compound and polymer encapsulation and is shown in Fig. 2. The sensing electrode element is made of silver on both surfaces of the sintered bulk ceramic

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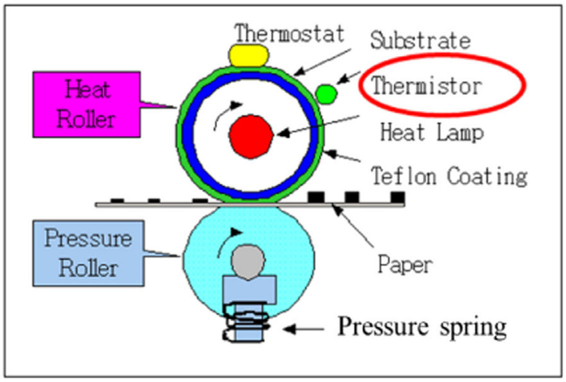

Fig. 1. Thermistor position in laser printer.

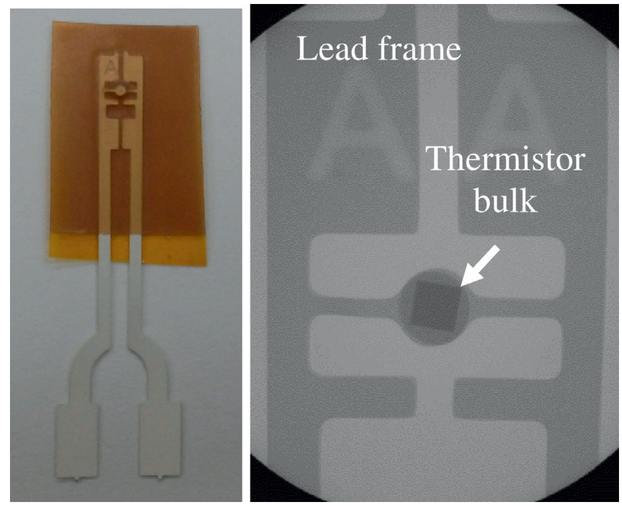

Fig. 2. Ceramic NTC thermistor for laser printer.

NTC thermistor. The silver is soldered to the metal lead frame, then the entire sensing part is overcoated with an epoxy compound to protect it from the external environment. Finally, a polyimide film is attached to reduce the abrasive stress.

4. Stress profile design for accelerated life test applied to thermal cycle and abrasion combined stress

The temperature profile of the thermal cycle for the accelerated lifetime test is shown in Fig. 3. Temperatures between 100 °C–160 °C are used for preheating and temperatures between 161 °C–210 °C are for paper printing. A time of 60 s and a rolling rate of 30 ppm (paper per minute) are used for this temperature range. Temperatures in the range of 211 °C–240 °C indicate an abnormal overheating at the end of the printing cycle. Between tests, the printing roller is cooled down to 100 °C by circulating air. Each cycle takes between 375 s and 415 s. The rotation rate of the heat roller was 60 rpm (revolutions per minute).

5. Design of accelerated life tester

An accelerated life tester which can apply combined stresses of thermal cycling and abrasion was designed based on the thermal cycling profile shown in Fig. 3. A halogen ramp within heat roller was used as a heating source for the thermal cycle. The same material of heat roller used in commercialized system was applied it this study.

The NTC thermistor for test (device under test) was attached to the surface of the heated roller of the accelerated life tester shown in Fig. 4, where the temperature change and rotating rate can be controlled by microcontroller firmware. Combined stresses, caused by the temperature change and abrasion at the contact point of thermistor and roller, is applied based on the actual operating condition of laser printer. 1-cylce stress is equal to 30 ppm printing operating condition. Therefore, durability under the combined stresses and the lifetime of the thermistor can be quantitatively co-related. Fig. 5 is the profile of the thermal cycle at the roller surface, taken from an actual operating condition.

6. Lifetime assurance design

Accelerated life testing is frequently conducted so as to predict the lifetime of a device. The frequency of applied stresses at an accelerated rate until failure gives critical information on assured lifetimes under normal operating conditions, as follows,

- B_1 life: B_1 life is the time at which 1% of units in a population will fail [11].
- Confidence level: 60%
- Number of sample for lifetime test: 92 (sample size calculated by B_1 and confidence level)

Table 1
The Simplified FMEA of ceramic thick NTC thermistor for laser printer.

No.	Design structure	Potential failure	Failure mode	Evaluation method
1	Sensor bulk	Void, micro-crack, macro-crack, non-uniform grain, Ion transfer, bulk shift	Temperature sensing error	High Temp/humidity/bias Thermal cycles Mechanical rolling stress (abrasion) ElectroStatic Discharge(ESD)
2	Electrode	Micro-crack, corrosion, electromigration		High Temp/humidity/bias, Thermal cycles Mechanical rolling stress (abrasion) Chemical contamination
3	Lead-frame	Restoring force decrease, corrosion		Thermal cycles Mechanical rolling stress (abrasion)
4	Encapsulation	Delamination surface wear		Thermal cycles Mechanical rolling stress (abrasion)

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