A novel reversible thermometric organic material for power transmission line detection application

Li Cheng*, Shang Ziwen, Wang Minzhen, Liu Li, Zhang Guangxin, Zhao Liyin, Ni Hongxia, Zhang Xiao, Zhang Jian, Qiao Dongliang
Changchun Institute of Technology, Changchun, Jilin Province, China
*Corresponding author’s e-mail: li.cheng@ccit.edu.cn

Abstract. Due to the inaccuracy of the existing fault detection method caused by the overheating of the equipment of the long-spanning overhead transmission line, this paper creatively proposes a detection method of the reversible thermochromic organic thin film material HCBCC which can be deposited on the equipment or hardware of the transmission line based on the electron transfer mechanism. In this method, the film material made with five components in accordance with the optimal ratio was named HCBCC film, and the coloration performance of the material was determined by UV-Vis absorption spectroscopy, temperature variable infrared spectroscopy, differential scanning calorimetry and other characterization methods. Then, its durability was verified through environmental tests such as high and low temperature, rain and snow, wind and sand, and aging. HCBCC material has the advantages of easy observation, fast color rendering and wide temperature range in the temperature indicator, which not only greatly reduces the intensity of inspection work for staff and can find fault points in time, but also saves a lot of time for the emergency repair of power equipment and provides guarantee for the safe and stable operation of power grid.

1. Introduction
The construction of the transmission line in China has been in the stage of rapid development. The lightning strike or short circuit fault would lead to arc corrosion at the key nodes caused the local heating is difficult to be observed by the naked eye or instruments. According to the relevant regulations, the maximum allowable temperature of wire and gold metal crossing the overhead transmission lines is 90 °C. Therefore, if the temperature exceed limit, it will cause damage to the transmission equipment and affect the working life, and even cause major accidents. In order to find the location of the fault point in time, it is urgent to need an effective method to enter the heating parts Line detection in time, eliminate potential hidden danger of power transmission system safety.

Toru Katsumata(2014)[1] used SiO2 glass fiber doped with Eu and Al to make optical fiber thermometers, whose measurement temperature principle is based on the temperature dependence of the luminous and visible photothermal radiation properties of the glass fiber. The fiber thermometer greatly improves the measurement range thermal radiation temperature measurement, but with low accuracy. C.Wen (2002)[2][3] used the multispectroscopic radiation temperature measurement algorithm for aluminum alloy property research and temperature measurement, which determined the characteristics and temperature relationship of aluminum alloy. N.Renault (2010)[4] developed an infrared temperature measurement method for high temperature heat sources, however it had low sensitivity when temperature below 20 degrees. F. Girard(2014)[5] extended the detection range of multispectral temperature measurement theory, selected various metal materials and different emission
models, and significantly reduced the temperature measurement error in the band range at 0.355μm-0.95μm. This indicates that the measurement range of multi-spectral radiation temperature measuring equipment is increased, and provides theoretical support and data analysis for temperature measurement in the ultraviolet region. Although some of these temperature measurement technologies have the advantages of high accuracy and wide range of temperature measurement, there are also defects such as high cost, tedious operation and poor stability, which make these methods difficult to popularize. This paper designs and manufactures a thermal chromic HCBCC material that can be used at low cost, high durability, good discoloration effect and wide discoloration temperature range, which can be applied to the surface of the monitored power equipment to show the long-term temperature change to achieve early warning or indication.

2. Analysis and preparation of HCBCC of reversible thermal chromic material

2.1 Material analysis and screening

2.1.1. Intramural proton transfer mechanism
At high temperatures, the molecular structure of the material changes as protons migrate, which results in the color change. The representative ones are salicylaldehyde aniline schiff bases. When the temperature rises, the hydrogen atoms on the phenolic hydroxyl group in the molecular structure will be transferred, so that the enol compound structure will change into ketone structure and form ketone-enol tautomer, thus causing the color change. Fig. 1 left shows changes in its molecular structure before and after the discoloration.

2.1.2. Electronic transfer
When the temperature increases, the color changing agent and the color developer will constantly conduct electron transfer, resulting in the molecular structure of the color changing material with a fixed absorption of light at some wavelengths to other structures, resulting in the color change. The material with the discoloration mechanism as fluorane, and the discoloration mechanism is shown in right in Fig. 1.

Therefore, according to the most suitable materials are mainly selected from three aspects: coloration mechanism, coloration temperature, and color contrast before and after coloration. Crystalline violet lactone, bisphenol A, high impact polystyrene, xylene and di-butanone were finally selected as the core parts of reversible thermochromic film materials. Among them, crystal violet lactone and bisphenol A as the color and color agent, high impact polystyrene, xylene and dibutanone as the solvent.

2.2 Material type selection and preparation
The quality ratio of high anti-resistant polystyrene (HIPS), crystalline violester, bisphenol A, methylene benzene, 2-butyl one will affect the performance of heat chromic films, so it is necessary to determine the best blending scheme and obtain heat chromic films with excellent effect. First, conduct the experiment strictly according to the complex scheme, and determine the discoloration temperature, speed and time of the complex compound. The steps are as follows:
(1) Determination of color interval: the test of color interval needs to call different ratios of color films of equal quality, and test the color temperature of reversible thermal color film respectively. During the test, the sample to be tested is divided into two parts, one for reference and the other in a petri dish and in a constant temperature water bath pot. Then, it gradually increased at the speed of 3℃/5 min, observed the color change of the color film, and tested the color film temperature in real time with an infrared thermometer to record the temperature when the color change was completely stopped, so as to determine the color interval. In order to reduce the experimental error, the test for the sample was been repeated four times to average of the test results.

(2) Determination of color time: adjust the temperature of the vacuum drying box to make it within the color temperature range of the changing film. The cooled petri dish was placed in the oven with discoloration from the film surface to record how long the sample needs to complete restoration.

(3) Determination of recolor time: place the film at room temperature and record the time from the initial color to the full return to the original color.

The test results are shown in Table 1.

| Sample number | Proratio | The temperature interval for changing the color(℃) | Fully change the color time (T/s) | Restore the color time (T/s) | The effect of changing the color | Rereversibility | Comprehensive evaluation |
|---------------|----------|---------------------------------------------------|----------------------------------|-----------------------------|---------------------------------|----------------|------------------------|
| 1             | 100:1:3:600:500 | 74~126                                           | 73                               | 64                           | Obviously                       | Good           | Excellent              |
| 2             | 100:1:3:600:400 | 73~125                                           | 73                               | 62                           | Obviously                       | Good           | Excellent              |
| 3             | 100:1:3:500:500 | 71~129                                           | 65                               | 56                           | Obviously                       | Excellent      | Excellent              |
| 4             | 100:1:3:500:400 | 70~124                                           | 62                               | 54                           | Very obvious                    | Excellent one  | Excellent              |
| 5             | 100:1:2:600:500 | 76~125                                           | 78                               | 65                           | Obviously                       | Good           | Excellent              |
| 6             | 100:1:2:600:400 | 74~124                                           | 79                               | 67                           | Obviously                       | Good           | Excellent              |
| 7             | 100:1:2:500:500 | 73~127                                           | 81                               | 70                           | General rule                    | Good           | Ordinary ones          |
| 8             | 100:1:2:500:400 | 73~126                                           | 82                               | 71                           | General rule                    | Good           | Ordinary ones          |
| 9             | 100:1:1:600:500 | 72~126                                           | 80                               | 71                           | General rule                    | Good           | Ordinary ones          |
| 10            | 100:1:1:600:400 | 71~125                                           | 80                               | 70                           | Obviously                       | Good           | Ordinary ones          |
| 11            | 100:1:1:500:500 | 72~128                                           | 77                               | 65                           | Obviously                       | Good           | Ordinary ones          |
| 12            | 100:1:1:500:400 | 70~127                                           | 80                               | 69                           | Obviously                       | Good           | Ordinary ones          |

3. Test and analysis of HCBCC materials

3.1 Analysis of the discoloration mechanism of HC BCC

From the experimental data of Table 2, the dosage of the film determines the color; the dosage of bisphenol A, xylene and 2-butylone determines the depth of the color of the compound, but the dosage of crystalline purple polyester plays a leading role; the dosage of xylene and 2-butylone determines the discoloration temperature of the reversible thermochromic material. According to the comparison of the five components, the optimal ratio of the five components is 100: 1: 3: 500: 400, and when the use of the solvent is less, the thermal chromic film discoloration is slow, which shows that the appropriate increase of the solvent under the allowable conditions, will change the thermochromic film Performance has a beneficial effect. To facilitate the formulation of this reversible thermochromic material, the film material made by the five ingredients according to the optimal ratio was named HCBCC films. The after discoloration are shown in Fig. 2.
3.2 Experimental test results analysis

3.2.1 Analysis of UV-visible absorption spectroscopy results
In the range of visible light, the optimal UV ratio of the visible absorption spectrum is shown in Fig. 3. At room temperature 25℃, there is a wider absorption peak in the wavelength range of 500-750nm, when the temperature rises from 25 ℃ to 70 ℃ is not obvious, the peak gradually decreases as the temperature continues to rise, each 10 ℃ for 70-90 ℃, compared to the other temperature intervals.

![Figure 3 UV-visible absorption spectra of HCBCC films](image)

3.2.2 Analysis of infrared spectrum observation variable temperature
The temperature changing infrared spectrum of the HCBCC film and the temperature changing infrared spectrum after image processing are shown in Fig.4a and Fig.4b. It is seen from Fig.4a that the increase in temperature rise in the range of 2300-2800cm⁻¹ leads to its reduced spectral band strength, indicating the reduced strength of substances such as carboxylic acid. When the reversible thermochromic film is in the range 1345-1380cm⁻¹, its temperature-varying infrared spectrum is shown in Fig. 4b, whose spectral band strength decreases with temperature, which also shows that the characteristic peak of the carboxylate also gradually decreases with temperature.

![Figure 4](image)

(a) Infrared spectrum diagram in the range of 2300-2800cm⁻¹
(b) Infrared spectrum diagram in the range of 1345-1380cm⁻¹
4. Study on online properties of HCBCC films

4.1 Line clamp coating process
In order to further verify the actual performance of HCBCC material online clamping, a series of experiments were carried out in this paper to verify its working effect in different external environments. In order to prevent the damage of HCBCC film by ultraviolet radiation, UV-531 ultraviolet absorber was used to enhance the anti-ultraviolet ability of HCBCC film. The UV absorber and epoxy resin were mixed at a ratio of 1 : 10 to make the anti-UV coating. The UV coating can absorb the UV light at the wavelength of 240 ~ 340 nm. In order to protect the performance of the wire clip and HCBCC film, this paper applies different layers of fire retardant paint, insulating paint and anti-ultraviolet resin varnish evenly on the wire clip. The line sandwich film structure is shown in Fig. 5 left part, and the applied finished product is shown in Fig. 5 right.

![Figure 5 Film structure diagram of clips and the sample of HCBCC film smear on the wire clip](image)

4.2 Performance test and aging test analysis in different environments
To simulate the complex environment after its actual installation, this paper place wire clips covered with thermochromic films in different environments as shown in Table 2 to detect their discoloration effect and performance.

| Environment Type | Start the Discoloration Temp (°C) | Color Change Time (s) | Full-colour Temp (°C) | Fully Color Discoloration Time (s) |
|------------------|-----------------------------------|-----------------------|-----------------------|-----------------------------------|
| Low Temp (No sunlight) | 77 | 49 | 97 | 66 |
| Low Temp (sunlight straight) | 78 | 50 | 95 | 67 |
| High Temp (No sunlight) | 73 | 49 | 93 | 66 |
| High Temp (sunlight straight) | 75 | 51 | 94 | 66 |
| Room Temp (No sunlight) | 71 | 50 | 91 | 65 |
| Room Temp (sunlight straight) | 70 | 51 | 90 | 66 |

According to Table 2, the thermochromic material has good discoloration performance, good discoloration effect, and is suitable for different complex environments, with high comprehensive value.

5. Conclusions
According to the characteristics of coloration mechanism, coloration temperature and coloration time of reversible thermochromic material, this paper designed and manufactured a thermochromic HCBCC material which can be used on overhead transmission lines with good coloration effect and wide range of coloration temperature. According to the discoloration experiment of HCBCC material, the optimal ratio, discoloration mechanism and discoloration time were determined. The discoloration performance was determined by ultraviolet spectrum analysis, infrared spectrum analysis and differential scanning calorimetry. According to the analysis, the best wire laminating materials and
structures of HCBCC films were obtained, and the properties were tested in different environments. The overall performance of HCBCC film is superior and the prospect is broad. In the future, it will have a very good development prospect in the overheat fault warning of power equipment.

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